

## VTT Technical Research Centre of Finland

### Telaketju

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RESEARCH REPORT

VTT-R-00062-19

# Telaketju - Towards Circularity of Textiles

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**Editors:** Pirjo Heikkilä and Marja Pitkänen

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<b>Summary</b> <p>Telaketju action was aiming for better utilization of textile waste. Telaketju Tekes project (4/2017-1/2019) was part of this action focusing on business opportunities. The common goal of Telaketju Tekes project was to facilitate textile (re)cycling and simultaneously create added value and new business around textile recycling and circular economy. Project consisted of company projects and public research supporting participating companies. This report summarised work carried out in Telaketju Tekes project supplemented with valuable findings and results from other Telaketju activities.</p> <p>This report includes description of circular textile ecosystem in Finland with future development needs and vision. It gives a summary of work carried out in order to build circular economy and sustainability know-how into Finnish companies, and research activities that aimed for facilitating textile recycling from collection and sorting to recycling processes. Furthermore, it includes description of large number of trials and demonstrations carried out by research organizations and companies. These demonstrations were largely carried out in co-operation between partners, and many of them formed chains, which model possible future value chains.</p> <p>Telaketju Tekes project successfully delivered one of its main expected outcome - to build a circular textiles ecosystem providing business opportunities, and composing of companies and other organization who have the necessary knowledge and urge to higher sustainability. Work towards higher circularity of textiles continues in companies and other organizations participated as well as linked with Telaketju network as well as in other Telaketju activities.</p>		
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## Preface

This is the final report of the *Telaketju Tekes project*. The Telaketju Tekes project was a part of the larger *Telaketju action*. The common target of the Telaketju action was better utilization of textile waste in Finland. This was carried out by launching simultaneously actions and R&D projects in textile collection and sorting as well as in processing and product development. The expected outcome of the Telaketju action was an ecosystem composed of companies and other organizations that have the necessary knowledge and urge to higher sustainability and to increase textile recycling in Finland. The common goal of Telaketju Tekes project was to facilitate textile (re)cycling and simultaneously create added value and new business around textile recycling and circular economy.

The Telaketju Tekes project was carried out during April 2017 - January 2019. The work was funded by Business Finland (formerly Tekes, the Finnish Funding Agency for Technology and Innovation). Project consisted of company projects and public research project. The research and development (R&D) partners of the project were VTT Technical Research Centre of Finland Ltd. (Tekes diary number 85/31/2017), Turku University of Applied Sciences (684/31/2017), and Lahti University of Applied Sciences (701/31/2017). The companies involved in the Telaketju Tekes project were Pure Waste Textiles, Recci, Remeo, Soften, Touchpoint, and Tramel with company project, as well as Ari Ilmakunnas, Finlayson, Infinited Fibre Company (IFC), Lounais-Suomen Jätehuolto (LSJH), MJV-Sähkö, Paptic, SOL Pesulapalvelut, Familon, Globe Hope, and Suominen with other contributions.

The Telaketju Tekes project was coordinated by VTT. The project manager was Pirjo Heikkilä (WP1 leader), and the responsible leaders were Kristian Salminen and Jani Lehto. The VTT key personnel included also Ali Harlin, Taina Kamppuri (WP3 leader), Eetta Saarimäki (WP4 leader), Sara Paunonen, Ville Hinkka and Jouko Heikkilä. The project manager at Turku University of Applied Sciences was Henna Knuutila and key personnel included Piia Nurmi (WP5 leader) and Inka Mäkiö (WP2 leader). The project manager at Lahti University of Applied Sciences was Kirsti Cura, and the key personnel included Jaakko Zitting, Niko Rintala, Lea Heikinheimo, and Minna Cheung. A large group of other researchers as well as technical staff participated in the project work, too.

The members of the steering group of the Telaketju Tekes project and the key persons from the companies participating in the project were Jukka Pesola and Noora Alhainen (Pure Waste Textiles), Juha-Matti Kykkänen (Recci), Eeva Perälä (WP6 leader) and Petteri Asikainen (Remeo), Sami Helle (Soften), Outi Luukko and Carita Peltonen (Touchpoint), Harri Niukkanen (Tramel), Oskar Engblom (Ilmakunnas), Elli Ojala and Sonja Lindqvist (Finlayson), Petri Alava (Infinited Fibre Company), Sini Ilmonen and Jukka Heikkilä (LSJH), Esa Taipale (MJV-Sähkö), Karita Kinnunen-Raudaskoski and Daniela Bqain (Paptic), Tiia Smolander and Kati Talikka (SOL), Maikki Lukka (Familon), Seija Lukkala, Elina Kuitunen and Miisa Asikainen (Globe Hope), and Mari Rahkonen (Suominen).

The Telaketju Tekes project co-operated with the parallel *Telaketju YM project* funded by the Ministry of Environment. The key persons in the YM project were Sini Ilmonen (project manager and the leader of Experiment 1), Miia Jylhä and Marko Kokkonen (the leaders of Experiment 2) from LSJH and Pia Engström (the leader of Experiment 3) from Helsinki Metropolitan Area Reuse Centre Ltd. The consortium & steering group of the YM project included also Turku University of Applied Sciences, Finnish Textile and Fashion, Finnish Environment Institute SYKE, Valonia, UFF rf, Ekopartnerit Turku, Pirkanmaan kierrätys ja työtoiminta ry, Turun seudun TST ry, Fida International ry, Suomen Kiertovoima ry KIVO, Lännen Tekstiilihuolto, Fortum Recycling and Waste Solutions, and City of Turku.

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Kochetkova, Eveliina Holopainen, June Juntunen, Linda Oksanen, Krista Virtanen, Emma Hirvonen, Nestor Ailoranta and Veera Konka from Lahti University of Applied Sciences; as well as Anneli Auranen from Metropolia University of Applied Science who made her thesis work at VTT.

Tampere 13.5.2019

*Authors*

## Contents

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<b>Preface .....</b>	<b>2</b>
<b>Contents.....</b>	<b>4</b>
<b>Abbreviations.....</b>	<b>7</b>
<b>1. Introduction .....</b>	<b>8</b>
<b>2. Telaketju Action .....</b>	<b>10</b>
2.1 Telaketju Tekes Project.....	11
2.2 Other Telaketju Activities.....	13
2.2.1 Telaketju YM project.....	13
2.2.2 Telaketju TEM Project .....	14
2.2.3 Telaketju AIKO Project.....	14
<b>3. Circular Economy and Sustainability.....</b>	<b>15</b>
3.1 Description of Circular Textile Ecosystem in Finland.....	15
3.1.1 Consumers and Other End-Users of Textiles .....	16
3.1.2 Lengthening Product Life.....	16
3.1.3 Collecting and Sorting .....	17
3.1.4 Recycling.....	18
3.1.5 Textile Industry, Brands and Retail Sector.....	20
3.2 Textile Recycling Ecosystem in Finland .....	21
3.2.1 Road-map for Recycled Textiles in Finland in 2020's .....	21
3.2.2 Centralized Sorting and Refinement Plant .....	22
3.3 Development towards Sustainability and Circularity .....	23
3.3.1 Circular Economy Knowledge in Telaketju Companies .....	23
3.3.2 Communicating Sustainability .....	25
<b>4. Facilitating Textile Recycling .....</b>	<b>28</b>
4.1 Textile Collecting.....	28
4.2 Identification of Textile Materials .....	28
4.2.1 Technologies for Textile Identification .....	28
4.2.2 Comparative Study of NIR Textile Identification .....	29
4.3 Sorting of Textile Waste .....	30
4.3.1 Fibre Composition Study by Manual Sorting.....	30
4.3.2 Sorting Quality in Manual Sorting .....	31
4.3.3 Composition Study with Automated Sorting.....	32
4.3.4 Sorting Quality in Automated Sorting.....	32
4.4 Textile Recycling Processes .....	33
4.4.1 Processes and Terminology .....	33
4.4.2 Suitability of Textile Waste for Recycling .....	34
4.5 Modelling of Costs.....	36
4.6 Risks Related to Recycling .....	37
4.6.1 Risk Management.....	37

4.6.2	Challenges in Building a Textile Recycling System .....	39
4.7	Safety Issues Related to Textile Recycling.....	40
4.7.1	Chemicals in Waste Textile.....	40
4.7.2	Occupational Safety in Textile Recycling.....	41
4.7.3	Dust Formation in Spinning Yarn from Mechanically Recycled Cotton .....	41
4.7.4	Dust Formation in Foam Laying from Mechanically Recycled Cotton .....	43
4.7.5	VOC in Foam Laying and Handling Foam Layered Materials .....	44
4.7.6	Surfactant Concentration in Airborne Dust.....	44
4.8	Regulation Related to Textile Recycling .....	45
4.8.1	Current Changes in the Finnish Waste Act.....	46
4.8.2	Current and future EU-regulations .....	49
<b>5.</b>	<b>Trials and Demonstrations .....</b>	<b>50</b>
5.1	Product Design.....	50
5.1.1	Creative Design Methods towards Circular Economy .....	50
5.1.2	Ecological Work Wear for Caring Industry.....	52
5.2	Mechanical Recycling Demonstrations .....	52
5.2.1	Opening and Air-Laying of Recycled Materials .....	52
5.2.2	Ring Spinning of Mechanically Recycled Fibres .....	54
5.2.3	Open End Spinning of Mechanically Recycled Fibres.....	55
5.2.4	Carded Nonwovens Made of Post-Consumer Cotton Fibres.....	55
5.2.5	Foam-Laid Nonwovens from Mechanically Recycled Fibres .....	56
5.2.6	Foam Formed Packaging Materials from Process Reject and Dust.....	59
5.3	Products form Mechanically Recycled Materials .....	60
5.3.1	Towels Made from Post-Consumer Jeans .....	60
5.3.2	Acoustic Panels Air Laid Recycled Mat.....	60
5.3.3	Padding Material for Backpack from Air Laid felt.....	61
5.3.4	Air Laid Felt as Alternative for Cardboard.....	62
5.4	Fibres from Chemically Recycled Cotton.....	62
5.5	Thermal Recycling.....	63
5.5.1	Composite from Work Wear .....	63
5.5.2	Testing of Blend Materials for Composite Production.....	64
5.5.3	Injection Moulded Textile Composite .....	64
5.5.4	Recycling Pillows and Duvets.....	65
5.5.5	Composites from Fluffy and Heterogeneous Textile Waste.....	66
<b>6.</b>	<b>Impact of Telaketju .....</b>	<b>68</b>
6.1	Dissemination Activities.....	68
6.1.1	Publications and Visibility in Media .....	68
6.1.2	New Projects.....	71
6.2	Networking of the Telaketju project .....	72
6.3	Feedback from the Companies.....	74
<b>7.</b>	<b>Summary and Conclusions .....</b>	<b>83</b>
	<b>References .....</b>	<b>88</b>

<b>Annex 1 Ring Spinning of Mechanically Recycled Fibres.....</b>	<b>91</b>
<b>Annex 2 Foam Laying Piloting with Textile Waste.....</b>	<b>94</b>
<b>Annex 3 Composite Materials by Modular Mixer .....</b>	<b>103</b>
<b>Annex 4 Dissemination Activities.....</b>	<b>111</b>
<b>Annex 5 Administration.....</b>	<b>121</b>

## Abbreviations

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CO	cotton
CV	viscose
Cr (VI)	chromium (VI)
CSR	corporate social responsibility
EC	European Commission
ECAP	The European Clothing Action Plan -project
ERDF	European Regional Development Fund
FIBS	Finnish Business & Society
FSWA	Finnish Solid Waste Association
FTIR	Fourier transform infra-red
GC/MS	gas chromatography-mass spectrometry
ICSC	international chemical safety cards
IFC	Infinited Fibre Company
ILO	International Labour Organization
IVL	Swedish Environmental Research Institute
Lahti UAS	Lahti University of Applied Sciences
LSJH	Lounais-Suomen Jätehuolto Oy
MFF	Mistra Future Fashion
NIR	near infra-red
PES	polyester
PFOA	perfluoro octanic acid
POP	persistent organic pollutant
PP	polypropylene
R&D	research and development
R-CO	recycled cotton
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
STM	Ministry of Social Affairs and Health in Finland
STJM	Finnish Textile & Fashion
SYKE	Finnish Environment Institute
TEKES	Finnish Funding Agency for Technology and Innovation
TEM	Ministry of Employment and the Economy
TUAS	Turku University of Applied Sciences
TSV-service	Subsidiary liability service of waste management
TVOC	total VOC
UFF	U-landshjälp från Folk till Folk i Finland rf (a non-profit, non-governmental humanitarian organization)
VOC	volatile organic compounds
WO	wool
WHO	World Health Organization
WP	a work package of the Tekes-project (WP1–WP6)
WRAP	The Waste and Resources Action Programme
ZRR	ZenRobotics Recycler

## 1. Introduction

---

The future textile sector will be facing a requirement for a transition from a linear economy towards a more circular economy. The global fibre demand has been in accelerating growth, but the production of new textile fibres cannot be increased sustainably. Additionally, textile waste is a huge global problem. Textile recycling is, therefore, an attractive option to resolve both of these problems - to find alternative raw material sources as well as to reduce the amount of textile waste.

The amount of discarded textiles in Finland was estimated to be 71.2 million kg in 2012, from which 23 % (16.4 million kg) was separately collected and sorted and 77 % (54.7 million kg) ended up in waste management (Dahlbo *et al.*, 2015). Separate collection of textiles was focused on re-usable textiles. Most of the material collected by charity organizations (11.7 million kg, ~ 70 %) qualified for re-use either in Finland (3.4 million kg) or abroad (8.3 million kg). In 2012, only 1.5 % of the discarded textiles (~ 1 million kg), was recycled. Around 20 % of the collected textiles ended up as municipal waste. Since then, the situation has changed. It can be expected that textile consumption and thus the amount of textiles discarded annually have somewhat grown. On the other hand, organic waste, including textiles, should have been diverted from landfills since 2016. Among other things, this has increased people's interest in textile waste and its utilization. Furthermore, European Commission announced in 2017 that its member states should organize separate collection of textile waste by 2025 (European Commission, 2018a). All this lays a good foundation for starting to build a new business ecosystem around circular economy and textile recycling.

The overall goal of a circular textile ecosystem should be to maintain the value of the materials as high as possible and with minimal environmental impacts (Fontell & Heikkilä, 2017). Effective recycling of textile materials on an industrial scale requires building new processes and technologies and new know-how. Multidisciplinary co-operation is needed to be able to build new value networks. Furthermore, a circular economy is not only about recycling, as it includes also a wide range of activities that lengthen the life-span of products and materials. New emerging circular ecosystems will provide opportunities for new kinds of businesses. Telaketju networking was targeting on building such an ecosystem.

Research activities related to textile waste rise in Finland in 2010's. *Texjäte* project<sup>1</sup> coordinated by Finnish Environment Institute (SYKE), for example, studied the textile waste flows in Finland. Telaketju networking was started in co-operation between two projects directly preceding Telaketju action: *The Relooping Fashion Initiative* project<sup>2</sup> coordinated by VTT (May 2015 - December 2017, funded by Tekes), and *Textile 2.0* project<sup>3</sup> coordinated by Turku University of Applied Sciences (2016, funded by e.g. Sitra, City of Turku, Ekokem i.e. currently Fortum, Lounais-Suomen Jätehuolto Ltd. and Jätelaitosyhdistys i.e. currently KIVO).

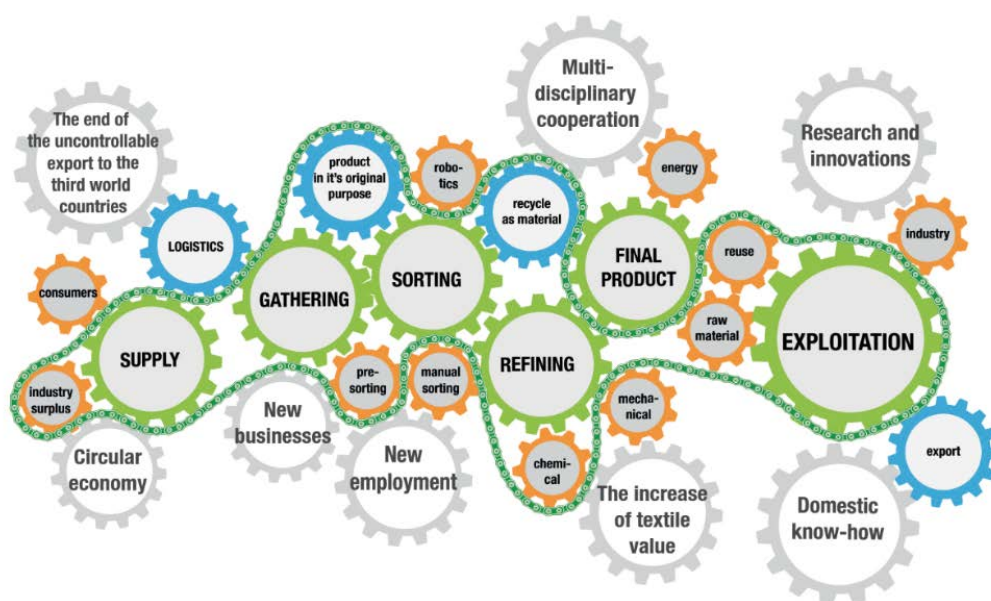
Telaketju research activities (*Telaketju action*) was comprised of several projects and funding types (Chapter 2). The Telaketju Tekes project was composed of *confidential company projects* and the *public R&D project*. This report summarises the work carried out in the *public R&D project*. The report includes also key learnings from the *Telaketju YM project* and some of the work carried out in the confidential company projects and directly linked with the public R&D project. Telaketju action also included *Telaketju TEM* and *Telaketju AIKO projects*, which started during the second half of the Telaketju Tekes and Telaketju YM projects. The focus of the first stage was on textile recycling, even though circular economy is more than just recycling. Figure 1 illustrates of the main activities, requirements and effects of a circular textile ecosystem.

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<sup>1</sup> <https://www.syke.fi/hankkeet/texjate>

<sup>2</sup> <http://reloopingfashion.org/>

<sup>3</sup> <http://poistotekstiili.turkuamk.fi/in-english/>



*Figure 1 A circular textile ecosystem: the main activities, requirements and effects*

The results of Telaketju Tekes and YM projects are presented under three chapters based on the selected themes. The themes are Circular Economy and Sustainability (Chapter 3), Facilitating Textile Recycling (Chapter 4), and Trials and Demonstrations (Chapter 5). Furthermore, the dissemination activities of the Telaketju Tekes project are described in Chapter 6, and the summary of the results and conclusions are given in Chapter 7. Many parts of the work have been published as separate reports or publications. In such cases, only summaries of these texts are included in the report.

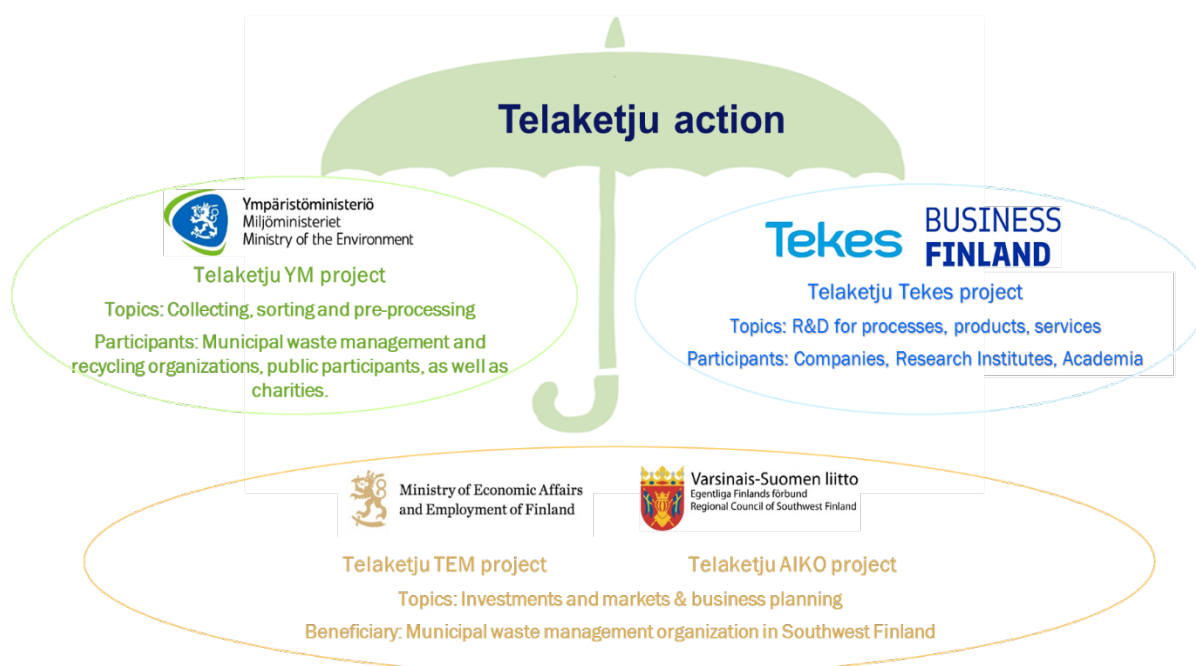
This report is public. It also include three public annexes containing more detailed description of demonstrations carried out by VTT: Annex 1 nonwoven demonstration with foam laying technology, Annex 2 about ring spinning demonstration, and Annex 3 about composite demonstrations with novel extrusion device, Modular Mixer. Annexes 4 and 5 are confidential summaries about dissemination activities and administration of the Telaketju Tekes project, distribution to partners and Business Finland only.



## 2. Telaketju Action

The common target of the Telaketju action was a better utilization of textile waste in Finland. This was carried out by launching simultaneous actions and R&D projects in textile collection and sorting as well as in processing and product development. The Telaketju action can, thus, be seen as an umbrella under which all Telaketju projects were networking and co-operating (Figure 2).

At first 2017-2018, the Telaketju action included two cooperating projects that had common tasks and linkages, i.e. the Telaketju YM project and the Telaketju Tekes project. The main funding bodies were The Ministry of Environment and Tekes/Business Finland. In 2018, two new projects funded by The Ministry of Employment and the Economy (TEM project) and Regional Council of Southwest Finland (AIKO project) were started. These projects focused on development of a refinery plant of end-of-life-textiles in Finland.



*Figure 2 The Telaketju action consisting at the end of 2018 of projects funded by the Ministry of Environment (3/2017-12/2018), Tekes/Business (4/2017-1/2019), Ministry of Economic Affairs and Employment (8/2018-7/2020) and Regional Council of Southwest Finland (5/2018-4/2019)*

We started building a new kind of multi-stakeholder business ecosystem around textile recycling. This will help the members of the Telaketju ecosystem and the Finnish society to transfer from the linear economy of textiles towards a circular one. Altogether 32 organizations were involved in the Telaketju YM and Tekes projects as partners or funders (Figure 3).

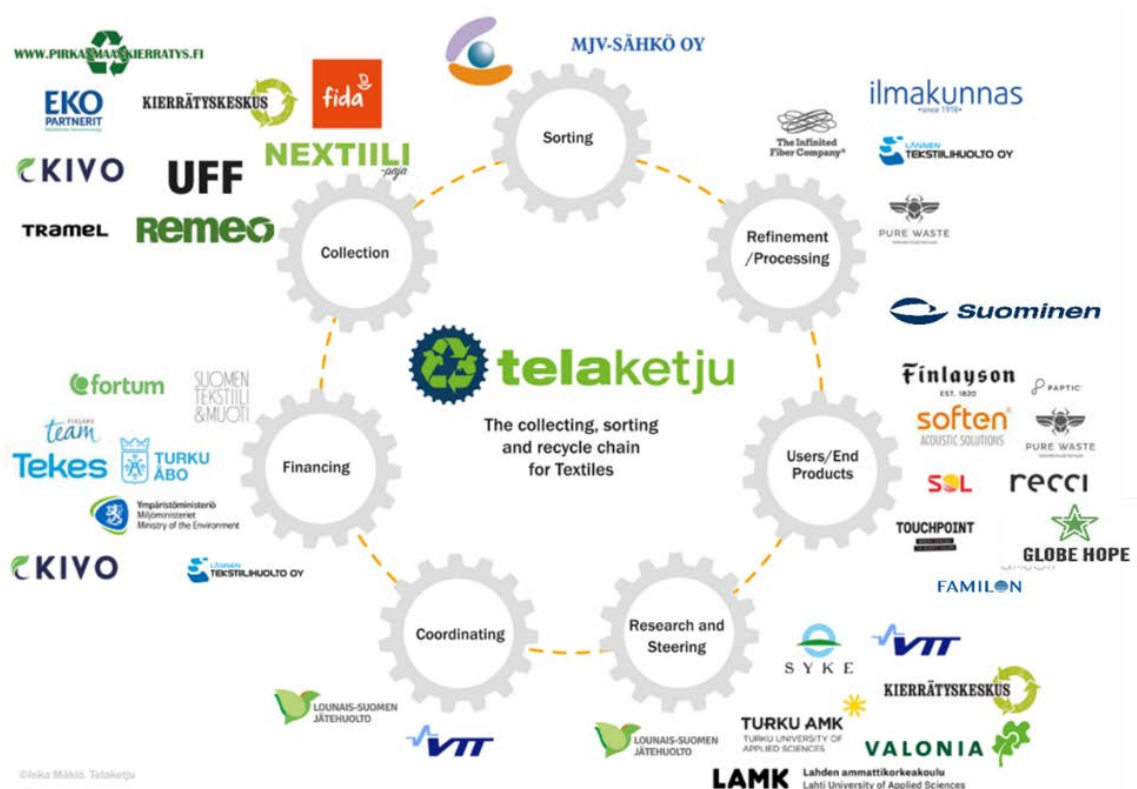


Figure 3 The organizations involved in Telaketju YM and Tekes projects in 2017–2018

## 2.1 Telaketju Tekes Project

Telaketju Tekes project targeted for development of new business opportunities based on circular economy of textiles. The common goal was to facilitate textile (re)cycling and simultaneously create new value chains, as well as added value and new business around textile recycling and circular economy. The main expected outcome of the Telaketju Tekes project was to build an ecosystem composed of companies and other organization who have the necessary knowledge and urge to higher sustainability and to increase textile recycling in Finland. In order to obtain its goal Telaketju Tekes project co-operated closely with the YM project. Telaketju consortium aimed also for active communication and publicity in order to increase the project's societal impact.

In order to reach this outcome the Telaketju Tekes project aimed to create/produce the following outputs:

1. Quality requirements for textile sorting
2. Specifications for sorted and pre-processed materials for industrial recycling processes
3. Product demonstrations made from a wide range of textile waste fractions
4. Tools for companies to introduce principles of overall sustainability in their business

The Telaketju Tekes project was composed of confidential company projects and the *public R&D project*, which included also contribution from the companies that participated in the project without a funded project. The companies with their own projects were Pure Waste Textiles, Recci, Remeo, Soften, Touchpoint, and Tramel. Their projects focused mainly on different phases of textile material recycling and/or service based circular economy business models and concepts. These company projects aimed for growth and competitiveness through new business opportunities, and targeted strongly at international co-operation and export markets.

The public research project was planned to help the companies to reach those goals by providing them better readiness for the transformation from a linear to a circular economy. The public R&D project partners were VTT Technical Research Centre of Finland Ltd. (VTT), Turku University of Applied

Sciences and Lahti University of Applied Sciences. The companies that participated in the project Ari Ilmakunnas, Finlayson, Infinited Fibre Company, Lounais-Suomen Jätehuolto, MJV-Sähkö, Paptic, SOL Pesulapalvelut, FAMILON, Globe Hope, and Suominen. The distribution of the total budget of the Telaketju Tekes project is shown in Figure 4. The public part of the Tekes-project was composed of six work packages (WPs), which are shortly described in Table 1.

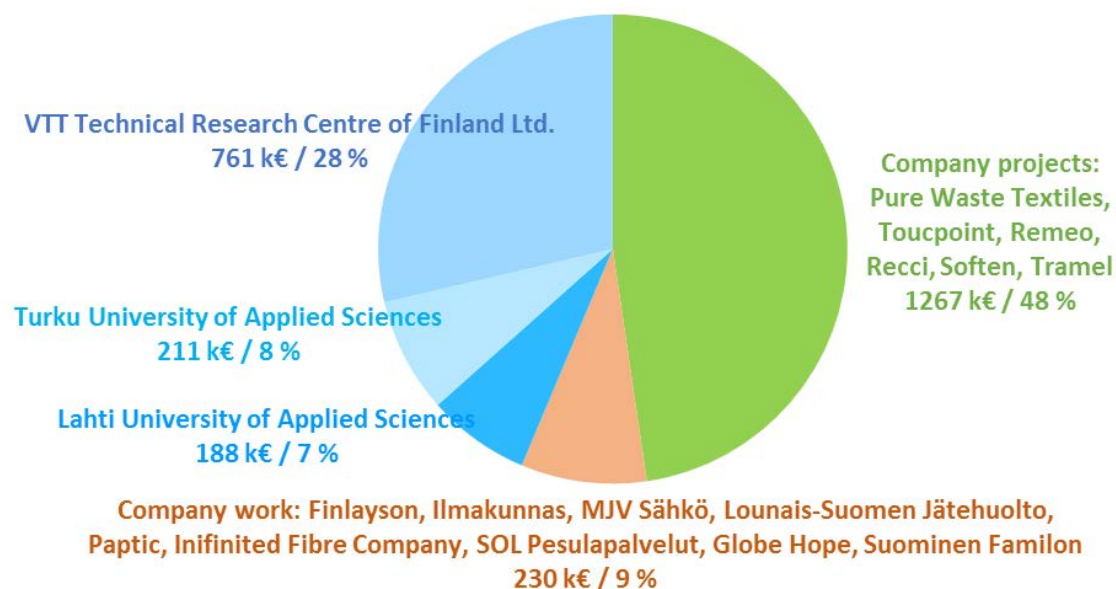


Figure 4 Division of the budget/value of work divided by type of participation. Public part of project is shown in blue and confidential company projects in green, value of work done by companies in orange

Table 1 The work package structure

No	Topics	Description and main activities
1	Management and networking	Included Telaketju Tekes -project management, networking of the companies, co-operation with the YM-project and other projects as well as networking with interest groups.
2	Building up circular economy knowledge and skills	Targeted to improve circular economy knowledge and skills of the participants. Included e.g. gathering information, making literature and other surveys, organizing webinars and workshops for the participants, modelling of the collection, sorting and pre-processing schemes (operating and logistic costs), and risk management.
3	Quality requirements and product specifications	Focused on sorting and processing of textile waste. Included determination of criteria for sorting, studying NIR and other technologies for textile identification, and creation of quality documentation for pre-processed textile materials.
4	Material demonstrations	Included demonstration of utilization of different textile fractions widely using different technologies, and production of different kinds of products for various applications.
5	Sustainability and safety	Focused on principles of sustainability and on how to communicate about sustainability. Included also a task that focused on occupational and product safety related to recycling processes and products.
6	Dissemination	Included communication about project and its results and launching new research activities exploiting the project results and built know-how.

## 2.2 Other Telaketju Activities

### 2.2.1 Telaketju YM project

In the Telaketju YM project, there were three Experiments implemented to support the circular economy of textiles. The project was carried out during 2017 and 2018. The project was named after the main funder, Ministry of the Environment. The other funders were the Finnish Textile and Fashion Association, Kiertovoima ry KIVO, Fortum Recycling and Waste Solutions, the City of Turku and Lännen Tekstiilihuolto Oy. The total budget of the project, including the partners' own contribution, was 205,000 €. The Telaketju ensemble enabled the follow-up projects Telaketju AIKO and Telaketju TEM. Telaketju YM project focused on consumer communications, clarification of terms and legislation on the field and on collection and sorting of end-of-life textiles (Figure 5).

#### A project for regional recycling experiments of municipal

### TELAKETJU

A collection, sorting and utilisation network for end-of-life textile

#### EXPERIMENT 1

Creating a national end-of-life textile recycling network and supporting its function

Lounais-Suomen Jätehuolto Oy with TUAS, Finnish Environment Institute SYKE and Valonia

#### EXPERIMENT 2

Regional textile sorting at the place of origin, textile reception and consumer communication

Lounais-Suomen Jätehuolto Oy with UFF, Ekopartnerit and TUAS

#### EXPERIMENT 3

Expertise for textile sorting – Textile sorter training \*Telakoulu  
Pääkaupunkiseudun kierrätyskeskus with Pirkanmaan kierrätys ja työtoiminta ry, Turun seudun TST ry, TUAS and Fida International

Advisory steering group with the Tekes project.

Executive board consisting of organisations and investors in the project

Other investors in the project:

The Finnish Ministry of Environment, Suomen Kiertovoima ry KIVO, Suomen Tekstiili & Muoti ry, Lännen tekstiilihuolto, city of Turku and Fortum Waste Solutions.

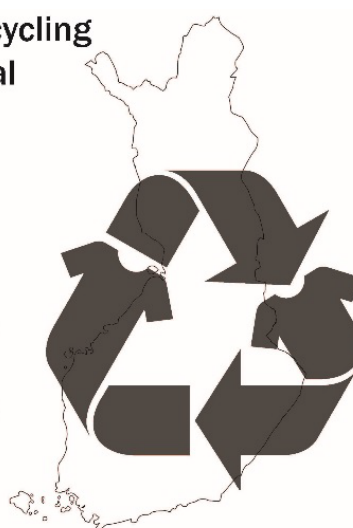


Figure 5 A summary of the three Experiments performed in the YM-project

The Experiment 1 focused on creating and supporting a nationwide textile recycling network. The responsible party was Lounais-Suomen Jätehuolto Oy, and the research partners were Turku University of Applied Sciences, Finnish Environment Institute (SYKE) and Valonia. This goal was shared with Telaketju Tekes project and work was carried out in co-operation.

The Experiment 2 focused on regional textile sorting, reception and consumer communication. The responsible party was Lounais-Suomen Jätehuolto Oy and the research partners were UFF rf., Ekopartnerit Turku Oy and Turku University of Applied Sciences. The factors effecting the quality of



the waste textile collected were investigated in this Experiment. The analysis were focused on different techniques and tools to collect waste textiles, and on customer communication. The results of this Experiment are summarized in Chapter 4.1, and they created a good base for planning a nation-wide collection network.

The Experiment 3 focused on expertise in textile sorting and textile sorting training. The content of the textile sorting training was designed and planned during the project. The training programme was piloted and implemented in Fida (Helsinki), TST (Turku), Helsinki Metropolitan Area Recycling Center and Pirkanmaa Recycling and Work Association (Tampere). Sorting pilots were carried out as part of the training, and the outcome (quality of sorting) was tested in cooperation with the Telaketju Tekes project. At the end of the project an online training material for textile sorting training and self-orientation of sorting sites was developed. Now textile sorting can also be studied as a part of a professional environmental qualification. As a result, there is a good starting point to arrange nationwide, good-quality sorting for end-of-life-textiles.

### 2.2.2 Telaketju TEM Project

The Ministry of Employment and the Economy (TEM) granted the Lounais-Suomen Jätehuolto Oy support targeting circular economy investment and development projects. The purpose was to launch an end-of-life textile processing plant project, with the intention of implementing the plant in phases. The project was seeking premises in Turku for the implementation of the first phase. The support granted to the project assist to acquire the equipment base for treating end-of-life textiles and processing them later on for the needs of companies both in Finland and on the international markets. The total budget of the project was 300,000 euros for investments and another 300,000 euros for development work. Since the processing plant was intended for the future treatment of end-of-life textiles coming from all over Finland, the project was funded also by the waste management companies of almost all the municipalities in Finland. With this project, the waste management companies were preparing for the EU Waste Management Directive amendment, according to which the separate collection of textile waste must be arranged by 2025.

The project started in August 2018 and last two years. It targeted to launch the end-of-life textile processing plant pilot and plan later phases. The project steering group comprised of the Finnish Solid Waste Association (FSWA) and member companies, VTT, the Turku University of Applied Sciences, the Lahti University of Applied Sciences, and Finnish Textile & Fashion.

### 2.2.3 Telaketju AIKO Project

The AIKO funding for launching new regional innovations and experiments, granted by the Regional Council of Southwest Finland to the LSJH, supports the implementation of the first phase of the Finnish processing plant for end-of-life textiles in Southwest Finland and the planning of later phases. This subproject is preparing a market survey for end-of-life textiles products, as well as the business plan of the plant. Its funding provides support for the development of high-quality sorting, so that the materials to be processed will meet the needs of companies utilising end-of-life textiles for new production. The total budget of the project is 73,000 euros. Lasting for one year, the project was launched in May 2018. The project steering group was the same than in Telaketju TEM project.

### 3. Circular Economy and Sustainability

A circular economy is based on three main principles: 1) designing out waste and pollution, 2) keeping products and materials in use, and 3) regenerating natural systems (Ellen MacArthur Foundation, 2018). In a circular textile ecosystem, discarded textile products and materials are kept in reuse and recycling loops, which maintains the value of the products and materials as high as possible for a maximum period of time. A circular economy is, thus, not only recycling, but includes resource efficiency and caring for environment. Circularity is, therefore, also closely linked with sustainability. ‘*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*’ (UN, 1987). The concept of sustainability can be considered to compose of three pillars: 1) economic, 2) environmental and 3) social, and thus when aiming for sustainable growth, all of these aspects of sustainability has to be considered.

This chapter firstly describes our vision Finnish circular textile ecosystem; its status and future as seen by the steering group of the Telaketju Tekes project (Chapter 3.1). It gives some visions for the future recycling and textile sector in general (Chapter 3.2). And furthermore, it describes activities carried out within Telaketju action in order to prepare Finnish textiles sector and recycling ecosystem for circular economy transformation and increased sustainability (Chapter 3.3).

#### 3.1 Description of Circular Textile Ecosystem in Finland

Telaketju action aims for building a circular textile ecosystem in Finland including both *product re-use* and raw *material recycling* loops. Term *re-use* refers to use of textile products in their original purpose, and can also include tuning and re-making of clothing items, while term *recycling* refers to utilization of materials - fibres or their raw materials - for production of new textiles within fibre-to-fibre recycling. The big picture i.e. this ecosystem with development needs is shown in Figure 6. In the following chapters, the vision for to different parts of the future circular textile ecosystem is discussed in more details. This review includes the current status and the work done in Telaketju so far, the future development possibilities currently in view, the research questions and will be discussed and described more detailed.



Figure 6 A circular textile ecosystem as described by the Telaketju Tekes steering group

### 3.1.1 Consumers and Other End-Users of Textiles

A circular economy requires more active involvement of consumers and other end users to product and material cycles. Consumption habits are currently focused on large quantities and low prices. Even though consumers might state that they value sustainability and recycling, this does not show in their consumption habits and behaviour of general public. However, there is already a small group of aware consumers whose who also consume according to their values. In order to make consumers and other users of textiles more aware, they need to get more information. Within the Telaketju action, we communicated with consumers and experts alike via blogs and webinars, but we know that more information given in a right form is still needed.

In order to get consumers more involved in a circular economy and textile recycling, they will need more information. If consumers and other end-users would have better understanding about sustainability, textile fibres and environmental impacts, they would probably make better choices and demand more sustainable textiles in the future. Information on the environmental impacts of different kinds of textiles it not easily available and, thus, this information needs to be made more accessible for them in understandable form. Consumer involvement can also be increased via services and new kinds of business models. Hopefully, consumers and other end-users of textiles will have higher appreciation of recycled and sustainable materials and of circular designs in the future. In addition, this appreciation should also show in their purchase decisions and willingness to pay. Various aspects associated with consumers and other end-users are summarized in Figure 7.

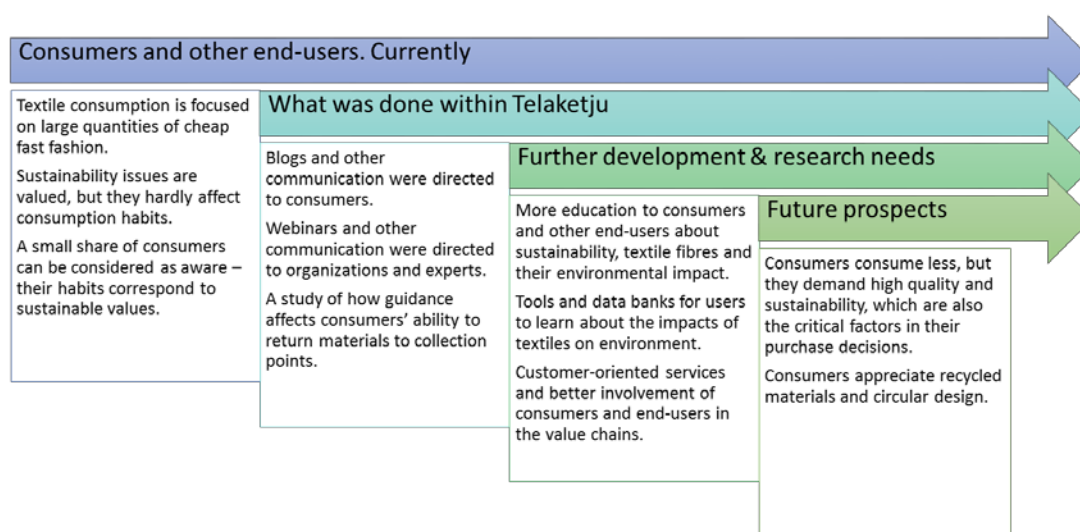


Figure 7 Consumers and other end-users

### 3.1.2 Lengthening Product Life

A circular economy aims for keeping the value of the products and materials as high as possible for as long as possible. In case of textiles, this means that textile products should be kept in use as long as possible and that they should be recycled as material only when they are no longer suitable for re-use purposes. This part of a circular ecosystem already exists at least to some extent. Re-usable textile products are cycled to new users via recycling centres, second hand shops, flea markets etc. In the past, second hand clothes were re-used and re-manufactured due to necessity, since textile products were expensive. Current fast fashion operation mode has lowered the prices. Furthermore, the low original quality of the current fast fashion items may, not even permit this kind of reuse of them.

Various charities and companies collect used textiles from consumers. Textiles of the highest quality are sold directly, and those of lower quality are typically exported into third world countries. Even though exported for reuse purposes, the fate of them is uncertain after exportation. Nowadays, this kind



of exports are thus sometimes considered as dumping of low quality textiles abroad. Thus, we think that when textile items, also those that are undamaged and clean, are seen as unattractive, it might be better to direct them to recycling rather than dump them abroad.

The designing phase of textile products determines how well and long they can cycle. Some textile brands have chosen to differ themselves from the mass by aiming for longer product life cycles and circular design. Within Telaketju Tekes project product design aspects were considered, for example, within webinars (Table 2, page 24) and demonstrations (Chapter 5.1). We see that in the future, focus should turn to these topics and slow fashion instead of fast fashion, and that this could be facilitated also via regulation and financial incentives. If textile products are available as a service, when the revenue for a producer or owner of the textiles comes, for example, from leasing fees, it is beneficial to produce durable and high quality materials and items. In addition to offering textiles as a service, maintenance and repairing services as well as different kinds of digital services and platforms, which enable consumer to consumer resale or share of useless textile items, are areas that can provide new business opportunities in the future. Various aspects associated with lengthening of product life are summarized in Figure 8.

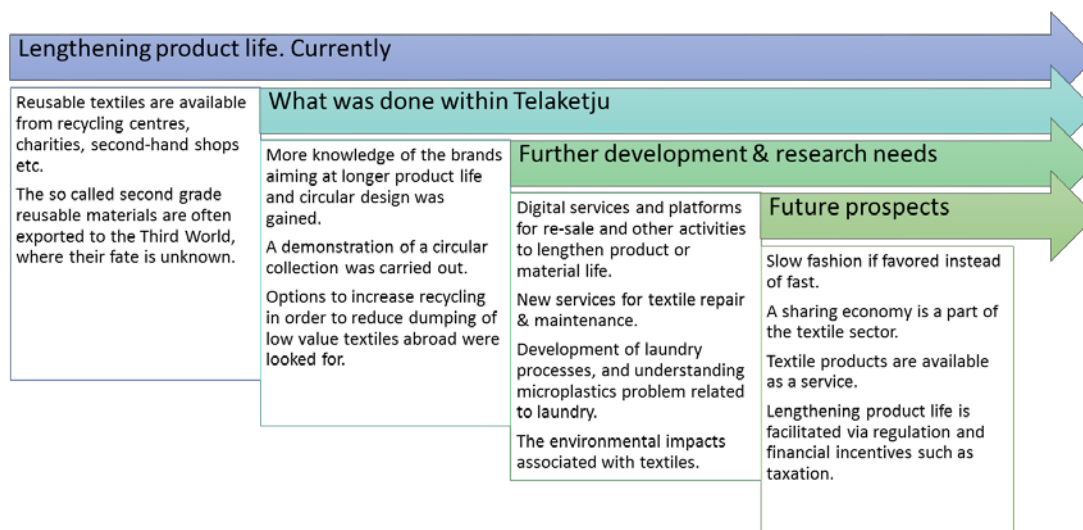


Figure 8 Lengthening product life

### 3.1.3 Collecting and Sorting

Regardless of if the intended utilization of textiles is re-use or recycling, discarded textile products need to be collected and sorted. Currently, we have a relatively extensive collecting point network covering at least the densely populated part of Finland. These collection options are mainly focused on re-usable items. However, especially when aiming for industrial recycling processes, the key to the profitable recycled material production is efficient collecting and logistics of textile waste materials. European commission is targeting for establishing a separate collection system for textiles within its member states by 2025 (European Commission, 2018a). Such a system can be arranged commercially, municipally, or in co-operation with different kinds of organizations.

Separate collection of textiles can be arranged in different ways, and the collecting scheme affects also the needs for sorting. Within Telaketju action, different collecting and sorting possibilities and methods have been discussed and studied. For example, different collection options have been tested in practice (Chapter 4.1) and the costs of them have been evaluated (Chapter 4.5).

Currently dominant method is manual sorting, which enable separation of high value re-useable items from lower value products. Most of the recycling processes are sensitive or selective to the fibre type, but manual sorting does not provide high accuracy nor high volumes. Therefore, when aiming for industrial recycling processes, where high accuracy in fibre recognition and high throughput are

essential, automated or semi-automated sorting is, thus, required. The current sorting lines, like commercially available Fibersort<sup>4</sup> and development stage SIPTex<sup>5</sup>, are based on NIR technology for the identification of textile materials. This technology has some drawbacks, but the development of the technology as well as combining manual pre-sorting with automated sorting are the options to overcome these current challenges. Also within Telaketju Tekes project identification (Chapter 4.2) as well as manual and automated sorting (Chapter 4.3) have been studied. If all textile products would have tags or chips in the future, like rental work-clothes and similar products already have, this would also help the sorting process. Various aspects associated with collecting and sorting are summarized in Figure 9.

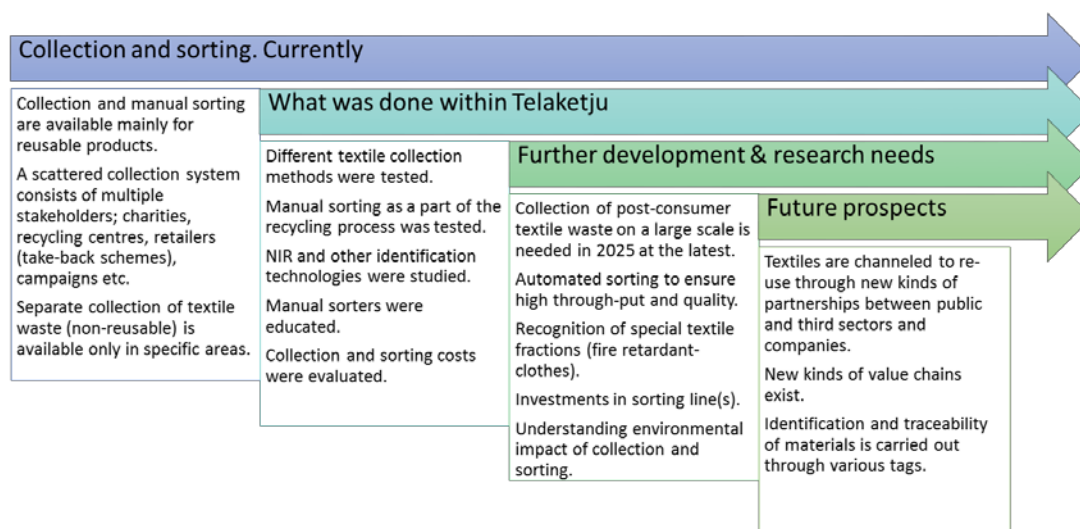


Figure 9 Collecting and sorting

### 3.1.4 Recycling

In Finland Dafecor<sup>6</sup> has done mechanical recycling for over 20 years, and some companies such as Globe Hope<sup>7</sup> and Touchpoint<sup>8</sup> as well as large number of designers who are making new products from used fabrics and other materials. Recycling of textile materials is still very marginal. According to Dahlbo *et al.* (2015), only 1.2 % of the textiles collected in Finland were recycled in 2012. The proportion of recycled textiles might have increased slightly due to new small actors within the field such as Partex-paja<sup>9</sup>, but due to lack of big actors, it is still quite small.

Almost all textile waste fractions need to be pre-processed for recycling. Knowing the origin and the history of a material makes it easier to decide how to process it. Used textiles might have been contaminated during use or collecting and transportation phases, which might be risk for personnel in recycling process or limit the possibilities for utilize such materials altogether or in selected applications.

Usually the first pre-processing step is cutting the products into pieces of fabrics. This is followed by tearing and opening the pieces into fibre level for mechanical recycling, or by grinding them into smaller pieces for chemical and melting processes. Removal of hard parts needs also to be done either before or after cutting the materials. Automated systems capable of removing hard parts require large volumes, while removal of them manually is time consuming and thus expensive. Only few processes, such as

<sup>4</sup> <https://www.circle-economy.com/case/fibersort/>

<sup>5</sup> <https://www.vinnova.se/en/p/siptex--swedish-innovation-platform-for-textile-sorting/>

<sup>6</sup> <https://dafecor.fi/>

<sup>7</sup> <https://www.globehope.com/>

<sup>8</sup> <https://www.touchpoint.fi/>

<sup>9</sup> <https://www.intopajat.fi/partex/>

VTT's development state Modular Mixer and extruder system (Chapter 5.5.5), can handle larger items or pieces of textile products also containing hard parts like fasteners if those too are made of plastic.

In order to support wider recycling of textile materials in industrial scale, development work and investments needs to be done. We also need to have more detailed information about different material fractions', including fibre mixtures, available in Finland. In principle, we should also be able to forward them into processes preserving their value, even aim for up-cycling referring to increase their value. In some cases textiles just cannot be recycled back to textiles or other valuable products. So production of chemicals and fuels, or utilizing textile as energy should be acceptable alternative for those textile waste fractions that are the most damaged, possibly contaminated or otherwise risky, as well as when the costs and/or the environmental impact of recycling processes are too high. Various aspects associated with pre-processing for recycling are summarized in Figure 10.

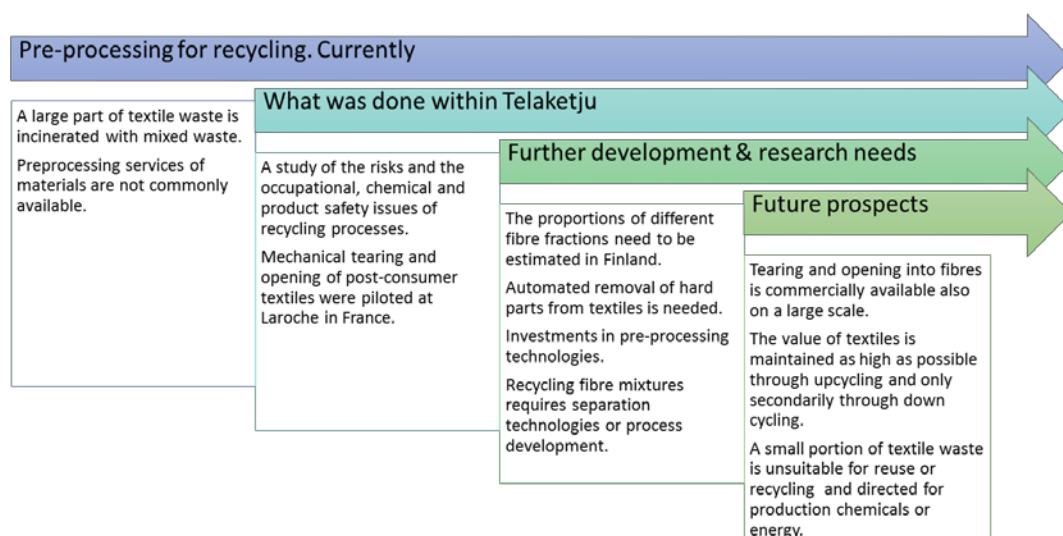


Figure 10 Pre-processing for recycling

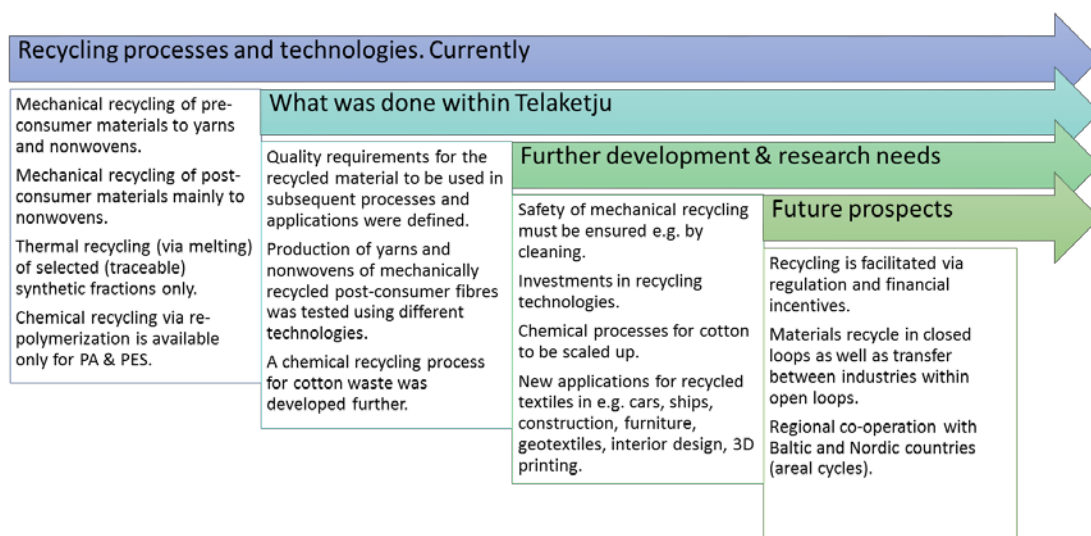
Textile recycling is currently focusing on mechanical recycling and pre-consumer textile fractions often into low value applications. We have, however, seen within Telaketju action that larger portion of discarded textile material can be recycled, as discussed by Kamppuri *et al.* (2019a) and shown by wide range for demonstrations carried out during Telaketju Tekes project (Chapter 5). Many of chemical and thermal recycling technologies are currently in development stage, for example, cotton recycling via cellulose carbamate technology (Heikkilä *et al.*, 2018) currently developed by Infinited Fibre Company<sup>10</sup> (Chapter 5.4) or via Ioncell technology<sup>11</sup>. Chemical and thermal processes are typically available only on a lab or pilot scale, and value chains are partly missing. Further development work and investments are, thus needed, in recycling technologies before whole value chains would be commercially available. As processes and value chains are developing, recycled materials can be used for a wider range of applications.

In order to make recycling-based businesses profitable, regulation and financial incentives may be needed. We see, however, that different kinds of closed and open recycling loops are the future. While basic textile industries, for example spinning of yarns, weaving and knitting, are no longer available in Finland, they are still available in Baltic countries. It is, thus possible to build a textile recycling hub in the Baltic Sea region. Furthermore, synergies could also be found in Finland, as recycling of synthetic textile materials could also be linked with plastics recycling in order to have larger volumes and wider

<sup>10</sup> <https://infinitedfiber.com/>

<sup>11</sup> <https://ioncell.fi/>

of raw material base for the recycling processes. Various aspects associated with recycling are summarized in Figure 11.



*Figure 11 Recycling processes and technologies*

### 3.1.5 Textile Industry, Brands and Retail Sector

In order to be able to switch to a circular economy and to answer to the anticipated raw material scarcity problem, a drastic shift has to happen in the textile sector. Currently, textile value chains are still very much linear, but interest in sustainability and circularity is rising. Unfortunately, in many cases talk about sustainability seems to be only green washing; for example, when large multinational organizations focus on selected topics, but are not yet adopting sustainability into all aspects of their business. However, it is clear that companies, especially small ones, take actions and move towards sustainability and circularity step by step. Being publically sustainable or taking actions towards it is not necessarily easy for companies of any sizes. Therefore, one objective of the Telaketju Tekes project was to equip the project consortium with more comprehensive understanding of sustainability and of how to communicate it (Chapter 3.3).

Inclusion of recycled fibres into yarns to partly replace virgin materials is an easy step towards circularity without a need to sacrifice quality. This kind of replacement is, thus, expected to be normal in the future. Product design is an essential factor in determining the fate of the textile products. An overall approach to have long lasting and eventually recyclable products is not too complicated, it just need the will to make right choices. For example, production of high quality materials and products combined with aesthetically pleasing, but timeless design helps to keep products circulating for a longer time. In addition, avoidance of unnecessary fibre mixtures, which are difficult to recycle, and unnecessary decorations made of various materials, for example, makes the recycling of the discarded textile products easier.

Furthermore, new kinds of business models and changes of ownership of textile products can shake the textile sector and consumption in the future. It will be beneficial to produce long lasting products, if the revenue for a textile company is made up of rental or leasing payments. Ownership accompanied with a responsibility for material recycling may remain in companies that provide textiles as a service.

Textiles as a service concept are slowly emerging and piloted, for example, by Mud Jeans<sup>12</sup> in Netherlands and Reima<sup>13</sup> in Finland. Various aspects associated with textile industry, brands and retail sector are summarized in Figure 12.

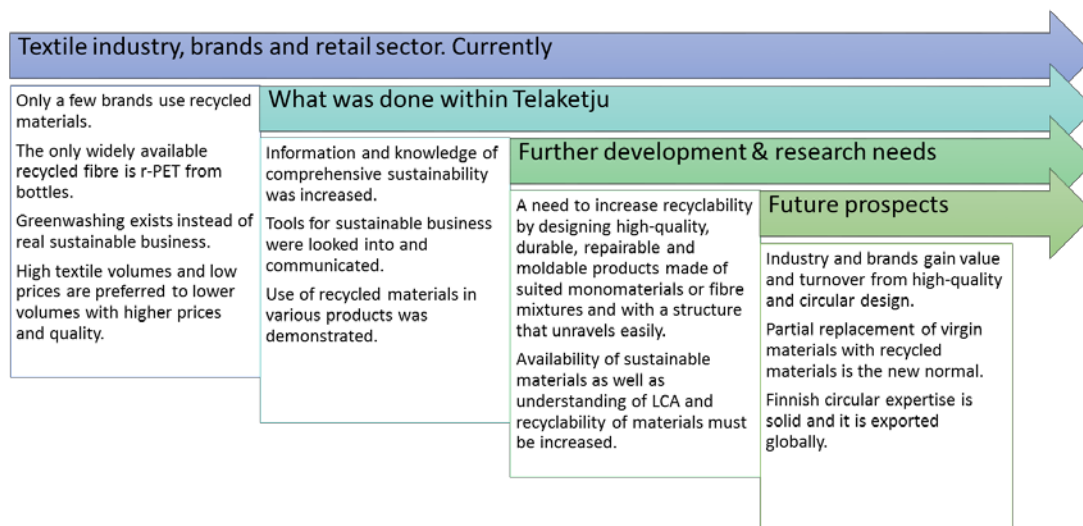


Figure 12 Textile industry, brands and retail sector

## 3.2 Textile Recycling Ecosystem in Finland

### 3.2.1 Road-map for Recycled Textiles in Finland in 2020's

Future prospects of Finland's textile sector relying especially on bio-based and circular economy have been evaluated (Harlin, 2018). In near future new materials and products based on renewable raw materials are expected to be a trend. Business is changing towards circularity, and while consumption habits change, also industry will adopt new operation paradigm. Landfill ban of organic waste in 2016 and separate textile waste collecting requirements in 2025 have set the time frame, but also recycling standards are expected to fasten change. Other drivers for change are, for example, waste crisis, unsustainability of cotton production and micro plastics problem related to synthetic fibres. Currently dominant technology, mechanical recycling, will be strengthened and increase, but circularity will be increased also in reuse via new business models and digitalization providing new opportunities for textiles services. New textile raw materials recycling technologies will be taken from lab and pilot scale to industrial scale also in near future. Bio economy solutions are rising in parallel with circular economy solutions. Finnish forest industry companies like Metsä Fibre<sup>14</sup> and Stora Enso<sup>15</sup> has taken a role in regenerated cellulose fibre sector. Finland can be reborn as textile country via renewable wood based fibres and circular solutions.

A road-map towards a future circular ecosystem is shown in Figure 13, and prospects for textile recycling routes and markets in Finland in Figure 14, and prospects for Finland as textile country in Figure 15.

<sup>12</sup> <https://mudjeans.eu/>

<sup>13</sup> <https://www.reima.com/int/company-contacts>

<sup>14</sup> <https://www.metsafibre.com>

<sup>15</sup> <https://www.storaenso.com/en>



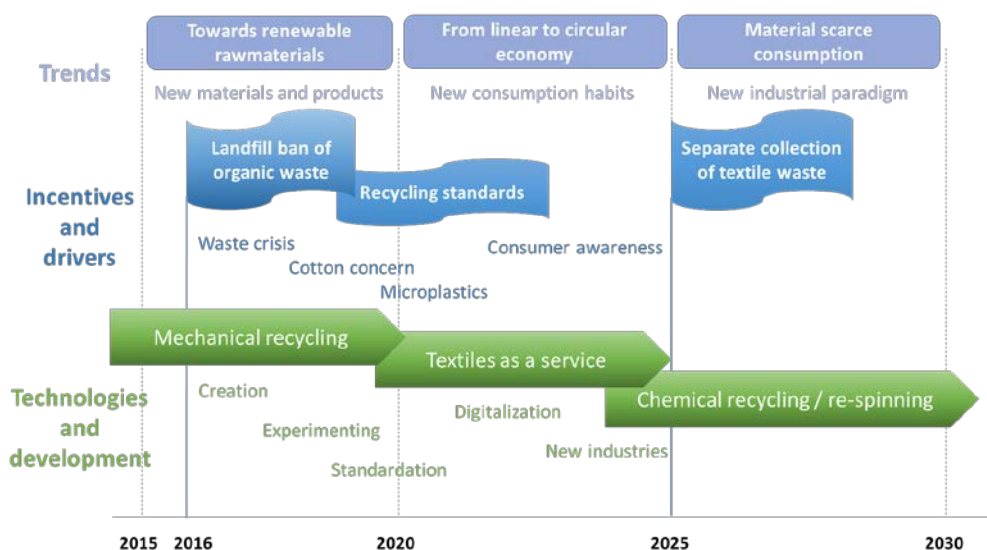


Figure 13 Roadmap for recycled textiles in Finland in 2020's. Re-drawn from Harlin (2018)

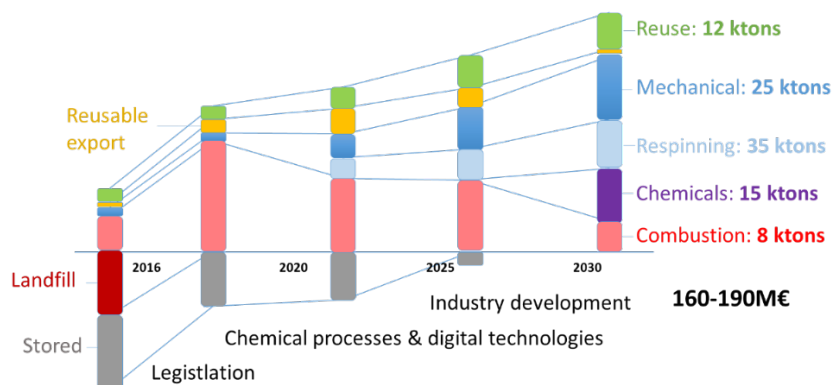


Figure 14 Textile recycling in 2020's. Re-drawn from Harlin (2018)

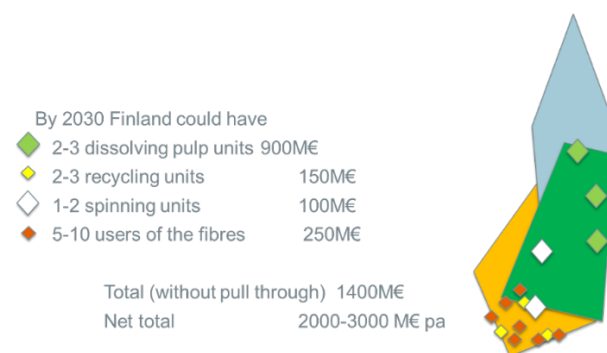


Figure 15 Finland as a future textile country (Harlin, 2018)

### 3.2.2 Centralized Sorting and Refinement Plant

Future steps of postconsumer textile refining in Finland are to be built, for example, in Telaketju AIKO and TEM projects. These project will cover first stage of processing plant pilot, idea of which is illustrated in Figure 16. It will include building facilities in Turku region and development of processing plant capable for sorting and handling of at least 2000 tons of textile waste material annually. Reuse and recycling target has set to 30-50% and the rest to energy. Aim is to continue stage by stage and have industrial scale operation ready by 2025 for separate collection of textile waste. (Heikkilä, 2018)

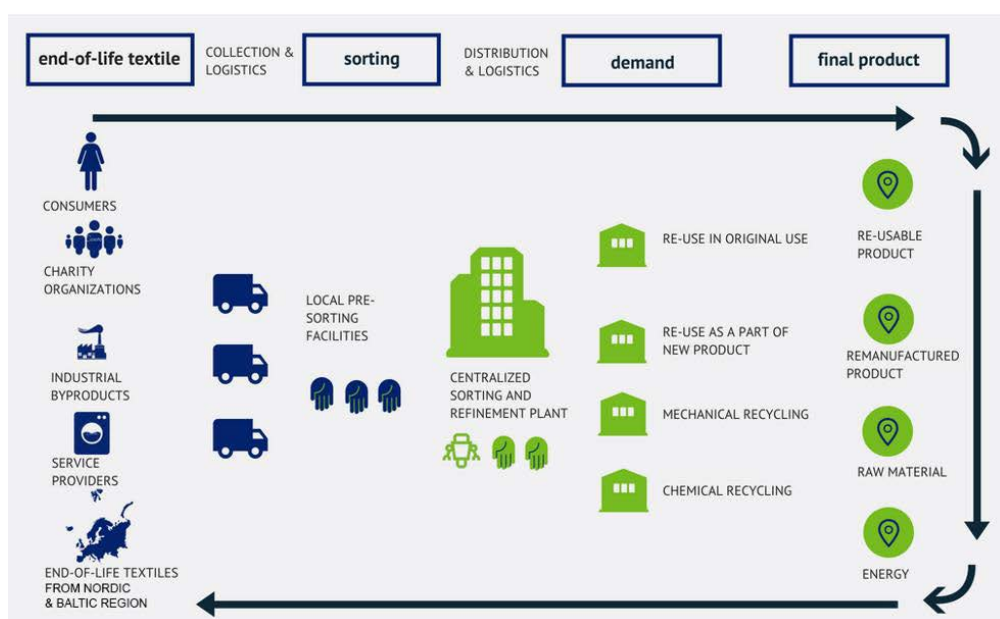


Figure 16 Idea for centralized sorting and refinement plant and its role in textile recycling scheme

### 3.3 Development towards Sustainability and Circularity

This chapter summarizes work carried out within Telaketju project to help companies move towards sustainability and circularity in general (Chapter 3.3.1) and to communicate sustainability topics (Chapter 3.3.2).

#### 3.3.1 Circular Economy Knowledge in Telaketju Companies

All the companies that participated in the Telaketju Tekes project were asked to define their starting point and the outcomes they expected from the project. The kick-off interviews were done between 29<sup>th</sup> May 2017 and 16<sup>th</sup> January 2018, and the interview questions were compiled around the six work packages that the Telaketju Tekes project is divided into. The common thread in most interviews was that the companies wanted to keep the project close to their everyday work and focus on the practical aspects of building a textile recycling ecosystem in Finland. One of the key challenges that was revealed during the interviews was the terminology that is used within the textile recycling field in Finland. The companies felt the terminology was familiar to them, and used similarly with similar companies. However, there were differences how some of the terms were used by companies and actors presenting different parts of the textile recycling chain. Many companies also worried that external communication might appear incoherent if common terminology is not used. Compiling a terminology guide (Salmenperä, 2017) that would include the terms that are related to textile recycling, explanations and synonyms, was proposed as a solution.

The companies were also asked to specify their need to increase circular economy knowledge within their company. Many companies were interested in stipulations for recycled material and certifications in textile industry along with legislation. Also, identification and quantification of environmental loads of, for example, virgin materials, was mentioned several times. Public procurements were of interest for the down-stream producers i.e. companies involved in collecting and sorting. A wide range of themes was discussed in the webinar series were held the whole duration of the Telaketju Tekes project. The webinar topics are listed in Table 2. The recordings and presentation materials, including the contact information of the presenters, are available in Finnish on the project's website<sup>16</sup>.

<sup>16</sup> <https://telaketju.turkuamk.fi/webinaarit/>



*Table 2 Topics and summaries of webinars held during the Telaketju Tekes project*

Topic, presenters and date	Summary
How is digitalization revolutionizing the textile industry? Satu-Marja Mäkelä, Juha Häikiö and Maarit Tihinen, 14.12.2017	Digitalization will affect all industry sectors, as well as consumer behaviour. In the near future, techniques such as 3D modelling, data analysis and customization of products will bring significant changes to the textiles, clothing and fashion sectors. Technology monitoring and resources are required to harness the benefits of digitalization.
Block chains: What are they and how will they change the textile industry? Kristiina Valtanen, 11.1.2018	Block chain technology is an innovation that has the ability to revolutionize the basic business mechanisms. The disruption that started in the financial sector is quickly spreading to other industries. Everyone should review the effects that systems of decentralized trust could have on their own business.
Benefits of Open Data for circular economy businesses - Examples from Finland and abroad, Piia Nurmi and Marika Säisä, 18.1.2018	Open Data refers to digital data sources, collected by public administrations, businesses and private individuals, that are open to the public for free use. Open Data opens up new opportunities for companies following circular economy principles.
Foresight as a key enabler in setting up circular economy solutions, Jouko Heikkilä, 8.2.2018	The transformation into circular economy opens up significant opportunities for promoting sustainability and developing businesses. However, successful utilization of these opportunities requires the identification challenges and threats, and the ability to utilize one's strengths ahead of the practical implementation of circular economy principles.
Ethical issues and corporate responsibility in the textile industry, Sade Hormio, 15.2.2018	The supply networks in the textile industry are spreading globally, usually to regions with the lowest unit costs. Questionable working conditions and inadequate occupational safety are the recurring problems in these regions.
Terms and administrative procedures of textile collection and recycling, Sirje Stén and Hanna Salmenperä, 13.3.2018	The renewed EU waste directive objectives address also textile waste recycling. Introduction of new collection systems of textile waste may require, e.g. new collection procedures. The webinar reviewed relevant terms and concepts, and the waste legislation for collection and export of textile waste.
The perspective of risk management in product design, Jouko Heikkilä, 19.4.2018	Roughly 80% of the total costs of a product is fixed already in the design phase. The recycling perspective brings more opportunities but also increases manageable risks to product design.
The operating environment and legislation in the textile and fashion sector, Satumaija Mäki, 24.5.2018	Practices of applying circular economy are rapidly evolving worldwide and in Finland. In addition to material recycling, product-related services enable new business models and earnings logics. The webinar presented, how textile recycling is promoted and the development of services is perceived abroad, and how increasing requirements and tightening legislation affect the operating environment of the textile and fashion industry.
How to make business out of textile recycling in Finland, Maria Antikainen, 27.9.2018	This webinar addressed challenges making business out of recycling: new business models, value creations etc. which require co-creation and innovation of business models and piloting of those.
What does the future hold? Transition into the circular textile economy is a systemic change, Kirsi Niinimäki, 11.10.2018	The webinar analysed the circular economy of textiles from the future perspective, and gave an overview of the main general trends and factors that either promote or prevent the transition. The fashion industry and business are undergoing a transformation that will change the operation of the whole textile industry.
Applying accountability in the product design process, Minna Cheung and Anniina Nurmi, 29.11.2018	A circular economy is not only about recycling used clothes, it is more about the choices the designer makes before there is no cloth at all. In this webinar two experts in fashion design gave different perspectives on how to approach sustainability and responsibility in a design process.

Furthermore, the Telaketju consortium was interested in ecolabels, and a review of them was carried out in the project (Haapala *et al.*, 2018). Textile ecolabels are in use on all continents, ecolabel requirements, monitoring and extend of use vary by the ecolabel. In total, 20 different textile ecolabels were found; 15 of them covered all textile materials, four covered only cotton and one covered both cotton and wool. Summary shown in Figure 17.



Figure 17 Various ecolabels of textile materials. Modified from Haapala *et al.* (2018)

### 3.3.2 Communicating Sustainability

According to specialist Anna Lemström from Finnish Business & Society (FIBS) (Kauppalehti, 2018), companies are often conservative when it comes to communicating about their responsibility acts. Lemström estimated that the underlying cause for this might be the fear of negative attention. Irina Niinivaara from EcoCompass also agrees on this estimate by stating that companies usually want to improve their activities first and then add in the communication about them. (Kauppalehti, 2018) However, according to the study Sustainable Consumption in Finland, carried out in 2014, almost all consumer groups are inclined to consume responsibly, and 53.5 % of the respondents can be influenced by marketing (Salonen *et al.*, 2014).

The companies in the Telaketju Tekes project wished to learn how to recognise the principles of responsible operations and how to communicate them. These issues were tackled in a series of workshops for the participating companies. The contents of the workshops were planned in co-operation with the companies to ensure that their educational needs were met.

In the spring of 2018, a three-part workshop & excursion series was arranged to the companies and other organisations involved in the project. It was facilitated by the circular economy expert company Ethica<sup>17</sup> and the communication and design collective Sustis<sup>18</sup>. The series covered topics related to sustainability, its implementation in companies and communication about it (more details in Table 3).

Table 3 Three-part sustainability workshop & excursion series

Type and time of the event	Theme
Workshop 13.2.2018	Your responsible and irresistible brand. Material (in Finnish) available on <a href="https://storage.googleapis.com/turku-amk/2018/04/vastuullisuus_netiti.pdf">https://storage.googleapis.com/turku-amk/2018/04/vastuullisuus_netiti.pdf</a>
Excursion 13.3.2018	Company excursion to Kotipizza, a company that has invested in responsibility, communication and transparency
Workshop 27.3.2018	When you are not ashamed, you can be transparent. Material (in Finnish) available on <a href="https://storage.googleapis.com/turku-amk/2018/04/lapinakyvyys_netiti.pdf">https://storage.googleapis.com/turku-amk/2018/04/lapinakyvyys_netiti.pdf</a>

Seven companies from the Telaketju network took part in the workshops. To make sure that the themes of the workshops would be put into practice, a blog series *Let's communicate responsibly!* was launched on the Telaketju website. Most of the companies that participated in the workshops, published blog posts there, reflecting on the theme of responsibility. The titles of the blog posts are listed Table 4. The *Let's communicate responsibly!* -blog posts have had 281 views by 15.2.2019.

Table 4 Blog posts published related to the sustainability workshop series

Organisation and date	Title (including translation)
Turku University of Applied Sciences, 16.5.2018	Helppo mutta niin kamalan vaikea vastuullisuusviestintä (Easy but so very difficult responsibility communication)
Finlayson, 11.6.2018	Finlayson haluaa olla maailman läpinäkyvin kodintekstiilialan yritys – mitä haluavat asiakkaat? (Finlayson wants to be the most transparent household textiles company – what do the customers want?)
Pure Waste Textiles, 18.6.2018	Yhdessä kohdatut haasteet vievät eteenpäin – kuluttajajätteestä kankaaksi (The Challenges faced together take us forward – from consumer waste to fabric)
Lounais-Suomen Jätehuolto, 18.6.2018	Asukas on tekstiilinkierrätysketjun ensimmäinen lenkki (The resident is the first link in a textile recycling chain)
Pääkaupunkiseudun Kierrätyskeskus, 3.7.2018	Työttömyys työllistämistyön toteuttajan silmin (Unemployment from the employment realiser's perspective)

The workshop series received a good feedback from the companies. The attendees found the discussions and hearing other people's thoughts and experiences most useful. Other useful sections in the workshops were the practical examples and exercises in responsibility communication and transparency presented by the facilitators.

In the fall of 2018, about half a year after the workshops, we asked the involved companies whether the series had had an impact on their responsibility actions and communication. According to the companies, the workshops had changed and reinforced their thoughts on the necessity of the topics. Two companies told that they had taken the lessons learned forward in the company, so that there will be discussion, ambition and finally action founded on the theme. Two companies told that they had utilized the

<sup>17</sup> <http://ethica.fi/>

<sup>18</sup> <https://sustis.fi/>

storification, a narrative technic, which came up in the first workshop, as a tool for their responsibility communication.

The workshops also increased companies' actions related to the themes. For example, one company reported taking part in the Fashion Revolution week (23.-29.4.2018), during which they also communicated strongly in social media and in their premises. The company maintains that these kinds of actions add to their transparency.

To inform the consumers about the circular economy of textiles, a series of seven blog posts were published during the year 2018 by the Telaketju YM project. The blogs were carried out with interviews. The topics of the blogs and the experts interviewed are collected in Table 5. A video series of seven episodes was also produced to support the topics of the blogs: What is end-of-life textiles, How to identify the materials, Durable textile, Take care of your clothes, After using, Be part of the chain, and A sustainable future for textiles.

*Table 5 Topics of the blog posts published during 2018 to inform consumers about the circular economy of textiles*

The topic of the blog	The experts interviewed
What is an end-of-life textile?	Hanna Salmenperä, SYKE
Textile materials	Rinna Saramäki, freelance researcher
Sustainable textile production	Niina Sinisalo, Kaino clothing brand
Textile maintenance	Katariina Juurikkala, Marttaliitto ry
Collection and sorting	Hanna Vänni and Päivi Lintula, Turun Seudun TST ry
National co-operation	Henna Knuutila, Turku University of Applied Sciences
Sustainable future of textiles	A compilation of the views of the interviewed experts

## 4. Facilitating Textile Recycling

Before the Telaketju action, the Finnish textile recycling ecosystem was diffuse and it was lacking certain vital pieces. Therefore, the common goal of the Telaketju action was to facilitate textile (re)cycling by acquiring information and know-how, and by developing processes and activities needed for the new value chains.

Within the Telaketju, we studied collecting of textile wastes (Chapter 4.1) and also focused the identification of textile materials and aimed for the creation of common criteria and tools for identification (Chapter 4.2) and sorting (Chapter 4.3). Similarly, we aimed for the determination of common quality requirements for the pre-processed materials to be used in industrial scale recycling processes (Chapter 4.4). Furthermore, the costs of the collecting, sorting and pre-processing steps were modelled for the comparison of different options (Chapter 4.5). Risks and safety issues of textile recycling were also reviewed (Chapter 4.6).

### 4.1 Textile Collecting

Separate collection of textile waste was tested as part of Telaketju YM project Experiment 2. A questionnaire for the inhabitants of the collection area strengthened the preconception, that the proximity and the facility of collection have a strong influence on people's waste sorting habits. At the end of this Experiment, 47 % of the respondents claimed they are sorting waste textiles always or usually, whereas in the beginning of the Experiment, the analogous number was 29 %. Also, the general willingness to sort waste increased somewhat during the Experiment, and the growth appeared here was bigger among the people who received encouragement and information material home. All measurable changes in people's attitudes or waste sorting habits were occurring during a long time frame. To enable a successful reuse and recycle of waste textiles, it is important to influence the public with long-term counselling.

The most reliable way to ensure the high quality in waste textiles collected, was to organise the collection indoors and with personal customer service. Collection points in the residential area showed also better outcome than other collection types compared. When collecting textiles in waste treatment centres, there emerged bigger amounts of other waste materials in the collection containers, and moisture in textiles, caused by failures in customers' sorting, unsuitable containers and too long emptying intervals. However, none of the container types examined here protected the textiles fully from getting damp. The quality of waste textiles collected can be improved by advising customers to pack the textiles waterproof and with frequent emptying the containers. Also, the circumstances in reception and storing can be crucial for the quality of textile.

### 4.2 Identification of Textile Materials

#### 4.2.1 Technologies for Textile Identification

Textile waste consists of many different polymeric materials. The sorting of the materials according to their composition increases the value of the recycled material, ensures its suitability for the different recycling processes and also guarantees the composition of the final product. To be sorted accurately, different materials have to be identified. The sorting of textile waste manually by means of attached washing tags is possible but slow. In addition, a large part of the material were unrecognized because the tag was missing or unreadable. With the automated sensor-based material identification, the sorting of textile waste becomes more efficient and its capacity increases. The identification of textile materials is well known in the context of quality control, forensic sciences and historical studies (archaeology, conservation). For these methods, the preparation of the sample is needed, for example in the standardised methods (see e.g. ISO 1833-1) to quantify different textile fibres the samples are dissolved for the analysis. The methods are accurate, but slow and require sample preparation, and thus unsuitable



for automated sorting of textile materials. A sensor suitable for automated identification must be able to measure the sample quickly, without sample preparation and even without contact with the sample, and the sensor must be sufficiently stable and reliable to operate under process conditions. Such sensors are generally based on spectroscopic methods like FTIR and NIR. The different technologies suitable for the identification of textile waste are reviewed in more detail by Kampuri *et al.* (2019b).

In the automated sorting lines, the material identification is mainly based on NIR technology. The advantage of this technology is the fast and non-destructive analysis of the material without any contact with the material. Generally, textile materials consist of organic compounds whose chemical bonds absorb light in the NIR wavelength range. Different textile fibres can be identified using NIR sensors in the wavelength range of 700-2500 nm. In an automated line, the material sensing sensor is only one part of the line. It must act synchronously with the line conveyors and sorting systems that separate different textiles according to the identified material composition.

The automated identification is based on the comparison of the unknown fibre material with a known fibre material. Usually, the known fibre samples are collected and measured to form a library of spectra, and they serve as control samples for the materials to be studied. For example, the NIR spectrum produced from the unknown sample is compared to the known spectra in the library and, if a match is found, the fibre type of the unknown sample is identified. Expanding the library is laborious and needs to be based on end users' needs. On the other hand, once the automated line has been adjusted and validated, it strengthens the sorting significantly and ensures sufficient material flows for further processing processes.

#### 4.2.2 Comparative Study of NIR Textile Identification

As part of Telaketju Tekes project and its international networking we carried out comparative study of identification of textile materials with NIR technology. The aim was to get better understanding of NIR technology in the identification of textile materials and its strengths and shortcomings related to textile properties. Work was carried out using set of over 250 textile samples, which were identified by REISKAtex® lab pilot by Lahti University of Applied Sciences, and SIPTex pilot<sup>19</sup> by the Swedish Environmental Research Institute (IVL)<sup>20</sup>. Selected samples were studied further by VTT.

Both identification systems had a NIR sensor for the acquisition of chemical data from the polymer material in the studied textile materials. The difference between the compared systems was the analysis of the collected data; and the libraries used. Ten library categories were selected (cotton 100 %,  $\geq 90$  %,  $\geq 80$  %, and  $\geq 60$  %; wool 100 % and  $\geq 70$  %; polyester (PES) 100 % and  $\geq 90$  %; and viscose 100 %). REISKAtex® and SIPTex lines were used for testing if the unknown sample was identified belonging any of the selected classes, for example piece of cotton fabric with 5 % of elastane should be identified in the  $\geq 90$ % cotton class. Majority of the samples (75 %) were identically identified with both SIPTex and REISKAtex®. The most of the deviating results seemed to be near the limits of different identification categories, and thus difference was caused by the different tolerance levels of the library categories of these two systems. Furthermore, large portion of these irregularly identifies samples have structural characteristics, which can explain differences in these results. These included properties such as decorative yarns of other fibre types, partial transparency of samples and coatings on textiles. Only less than 7 % of the samples gave irregular identification result without clear and/or probable reason.

NIR technology seems relative reliable method for identification of homogeneous textile samples including blends, however, heterogeneity of textile products is making automated NIR based identification systems more challenging. More detailed analysis will be published in a scientific article.

<sup>19</sup> <http://boergroup-recyclingsolutions.com/projects/siptex-swedish-innovation-platform-for-textile-sorting/>

<sup>20</sup> <https://www.ivl.se/>

### 4.3 Sorting of Textile Waste

#### 4.3.1 Fibre Composition Study by Manual Sorting

In the study carried out by Turku University of Applied Sciences, two samples of post-consumer end-of-life textiles brought by consumers to the waste treatment centres and sorting stations in Southwest Finland were studied. Lounais-Suomen Jätehuolto provided the material for the study. The aim of the study was to clarify the composition of the material available for material recovery in terms of fibre content. The size and weight of the textiles were also determined. In addition, the objective was to determine the limits of manual sorting based on washing tags of the textiles. The third aim was to determine, what kind of machinery would be suitable for moving textiles on an automatized sorting facility.

The study was conducted in two parts; the first part took place in summer 2017 and the second in spring 2018. In both parts of the study, a sample of 1000 kg of textiles was sorted. The textiles were first sorted according to the recycling instructions of Lounais-Suomen Jätehuolto. According to them, unusable dry clothes and household textiles packed in plastic bags are *end-of-life textiles*, and unusable rugs, accessories, underwear or socks, pillows, blankets, and padding are *discarded waste*. The proportion of end-of-life textiles in the two material samples was 93 % and 81 %.

The textiles that were classified as *end-of-life textiles* were further sorted by their fibre composition, which was verified from the washing tags (Figure 18). The textiles whose fibre composition could not be determined due to a missing or unreadable tag were sorted into their own group. A good one third of the textiles belonged to this group. A significant share of the textile resources may thus remain untapped. In addition, the products that consisted of more than one material layer formed the last group.

The fibre composition of the textiles that had been identified based on their tags was further verified using infrared (IR) spectroscopy. The number of various fibres and fibre blends was relatively high in the material, about 200. Cotton and polyester were the most common fibres. Supplementing manual sorting with mechanical could make textile sorting more feasible on a larger scale in terms of speed, volume and costs.



Figure 18 Sorting post-consumer end-of-life textiles



### 4.3.2 Sorting Quality in Manual Sorting

Manual sorting was piloted in Telaketju YM project as Experiment 3. The education for textile sorters pilot project was titled *Know-how for sorting textiles* (Telakoulu). The sorting pilot projects were executed in four partner organisations: Pääkaupunkiseudun Kierrätyskeskus Oy (the coordinator of the pilot), Fida International ry, Turun seudun TST ry/Texvex, and Pirkanmaan kierrätys ja työtoiminta ry/Nextiili. In addition, Turku University of Applied Sciences assisted in documenting the project.

During the sorting pilot, three practical one-day experiments were executed, and their main themes were efficient sorting (recognizing the material by hand), precise sorting (material identification from the material tags) and separating the vendible products. The sorted material fractions of the first two days were wool, cotton, polyamide and polyester. In the vendible separation experiment, the fractions consisted of vendible textiles, textiles potentially containing hazardous chemicals as well as of textiles suitable and unsuitable for recycling. The piloting days were monitored with the pre-agreed questions and documentaries. The quality control related to pilot was done by Lahti University of Applied Sciences.

In total, 9868 kg of textiles was sorted in the pilots, of which approximately 300 samples were picked and sent to Lahti University of Applied Sciences. The materials were identified with IR-spectroscopy, using Bruker's FTIR spectrometer.

As a result of the quality control, the Telakoulu pilot decided to recommend that in manual sorting the focus should be on reusable textiles. This would enable maximizing both the economic benefits and savings on natural resources. However, the important role of manual sorting as a part of sorting end-of-life textiles was acknowledged, as it can be used to effectively separate different textiles. One target for manual sorting in the future could be pre-sorting i.e. removal of vendible, potentially chemically hazardous and products not suitable for the recycling processes out of the textile waste material flow. Some general quality criteria for the sorting of recyclable fraction are collected to Table 6.

*Table 6 General qualify criteria for recyclable textiles*

Qualify Criteria	Explanation / Reasoning
Odour - must not smell	In the manual sorting mouldy or otherwise contaminated materials can cause an occupation health risk
Materials to be avoided:	
a) Multi-layered and coated textiles	Not suited for the automated identification
b) Materials that are difficult to process	Fractions that have been identified as potential chemical risk fractions (soft prints, coated textiles, dyed leather)
c) Prohibited substances such as fire retardants	<ul style="list-style-type: none"> <li>May include e.g. restricted brominated substances (max. allowed amount 10 mg/kg)</li> <li>Potential products safety / health risk</li> </ul>

Education textile sorters was also piloted in the Telakoulu experiment. Based on the education pilot, recommendations were made for the reform of the vocational schools in Finland, when the grounds for the vocational degree on Environmental maintenance were renewed during 2018. Telakoulu recommended that the part 'Collection and reclaim of materials' of the degree should be revised so that it could be applied for textile sorters in the future. Including the sorting knowledge as a part of the formal school system was considered important in order to raise its valuation. Having well-educated sorters will ensure that the sorting results will be of uniform quality, which is important for further refinery of them. Good sorting will also enable a more efficient reuse of the material and bring economic sustainability.

### 4.3.3 Composition Study with Automated Sorting

Automated sorting trials of textiles was carried out with ZenRobotics' sorting line at Remeo's sorting station in Helsinki. The objective of the sorting experiment was to study how ZenRobotics Recycler system (ZRR) separates different textile materials from each other. The system has thus far been used to separate large pieces of wood, metal, stone, plastic and cardboard from industrial demolition waste. The textiles studied here were manually sorted, as described in Chapter 4.3.1, into the following eight classes: cotton > 90 % and 50-89 %; wool; polyester > 50 %; acrylic > 50 %; polyamide > 50 %; viscose > 50 %; and others. First, ZRR robot was trained to recognize textile materials by running the different textiles under the sensors. Second, the accuracy of the sorting was studied by selecting four different classes to be sorted. After each run, the accuracy was determined. The results are collected in Table 7.

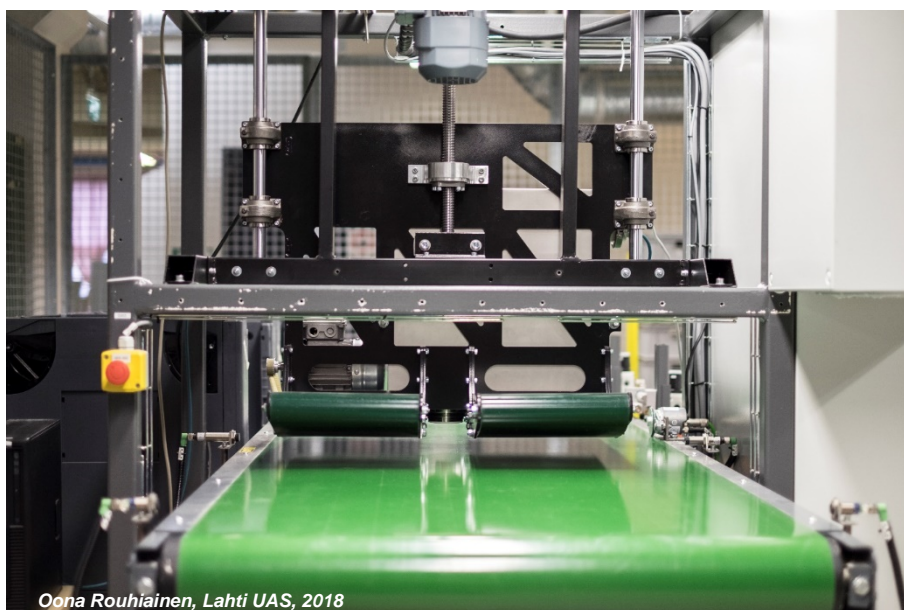
*Table 7 Sorting classes in different runs and the sorting accuracy*

Selected sorting classes		Accuracy
Class 1	cotton > 90 %	92.2 %
	cotton 50-89 %	91.1 %
	wool	99.6 %
	polyester > 50 %	93.5 %
	acrylic > 50 %	98.8 %
	polyamide > 50 %	97.7 %
	viscose > 50 %	97.7 %
	others	99.3 %
Class 2	cotton > 90 % + cotton 50-89 %	98.2 %
	all other materials to class others	98.2 %
Class 3	cotton > 90 % + cotton 50-89 %	96.7 %
	wool	99.8 %
	polyester > 50 % + acrylic > 50 % + polyamide > 50%	96.8 %
	all other materials to class others	99.0 %
Class 4	cotton > 90 %	94.0 %
	cotton 50-89 %	94.1 %
	all other materials to class others	96.7 %

The results were promising: ZRR robot was able to separate different materials with an average accuracy of over 90 %. In addition to the separation, the lifting up textile pieces off the conveyor was tested, i.e. whether it was able to pick up and sort the pieces of clothing into correct fractions. It should be noted that in the future the movement of the robotic arm should be programmed to do a lifting and lowering movement instead of throwing.

### 4.3.4 Sorting Quality in Automated Sorting

Lahti University of Applied Sciences has developed an automatic sorting unit for textile waste, REISKAtex® (Figure 19). The unit consists of an NIR analyser, a conveyor belt and pressurized air deflectors to sort the identified textile materials into the designated bins. Unblended fibres have been found to be the most prominent materials for textile recycling. Therefore, the REISKAtex® -system is designed to separate 100 % cotton, polyester, wool, and viscose, as well as some common polyester-cotton i.e. polycotton blend in different ratios from heterogeneous textile waste stream. During the development and testing of the automatic sorting unit, it was observed that in addition to the chemical composition of the fibres, the physical properties of the textiles (e.g. density, weave structure etc.) have an effect on the measurements, too. Therefore, the identification algorithm must allow slight variation in the spectral evaluation. These tolerances can be also adjusted to allow blends, with small percentage of other fibre, to pass as 100 % category in order to increase the yield of the sorting operations. The best throughput for sorted textiles is achieved when blend percentages of 1-5 % are accepted for 100 % identification.



*Figure 19 REISKAtex®, an automatic sorting unit for textile waste developed at Lahti University of Applied Sciences*

In its current development phase, the REISKAtex® sorting unit is capable of sorting approximately 100 kg of textile waste per hour. The test runs have been conducted using discarded textiles from the consumer collections carried out by Lounais-Suomen Jätehuolto. The purity and accuracy of the sorted cotton were examined during the sorting test runs by visual and haptic inspection, as well as afterwards by laboratory testing on random samples. Out of materials identified as 100 % CO (112.7 kg and 34.7 % of all measured waste textiles), 14 samples (i.e. 8.7 %) were taken aside for further inspections as suspected misidentifications. Four samples out of 14 samples contained impurities, including elastane, linen or protective chemical coatings. The results indicate a high accuracy in sorting, which enables high value recycling processes for both mechanical and chemical recycling. Adjusting tolerances to rule out all impurities would result in unnecessary discarding of pure cotton materials and a lower yield in recyclable feedstock.

The development of the automatic sorting system will continue by including more material classes for the sorting and by designing a faster and more reliable operation by improving the logical control programming.

## 4.4 Textile Recycling Processes

### 4.4.1 Processes and Terminology

There is no consensus on the terminology of the textile recycling processes. Ellen MacArthur Foundation (2017), for example, divides the textile recycling methods into the mechanical, polymer level and monomer level recycling. Another possibility is to divide the recycling methods according to the process type into mechanical, thermal and chemical recycling (e.g. Fontell & Heikkilä, 2017). The *mechanical recycling* refers to recycling at the fibre level, which means that textiles are opened back to fibres that can then be used for the production of new textiles. The *polymer level* recycling can be carried out by a *thermal* melting process or by a *chemical* dissolution process. The *monomer level* recycling is always a *chemical process*.

The terminology of textile recycling differs from the terminology used in plastic recycling. In the plastic sector, the term *mechanical recycling* refers to recycling of waste plastics into new, *secondary* raw material without changing the basic structure of the material. In practise, this means recycling of plastics

at the polymer level and using melting processes. Other terms are *material recycling*, *material recovery* and *back-to-plastics* recycling. (European Bioplastics, 2015). In case of textile recycling, the processes for the polymer level recycling are *thermal melting process*, and *chemical dissolution process*. The chemical recycling of plastics refers to recycling of waste plastics into monomers or other chemicals. The processes include, for example, chemolysis, pyrolysis, fluid catalytic cracking, hydrogen techniques and gasification (Ragaert *et al.*, 2017).

#### 4.4.2 Suitability of Textile Waste for Recycling

According to the waste hierarchy, the lengthening the lifetime and reuse of the textile products is the best option. When textiles are no longer suitable for the reuse, it is possible to create a new life cycle for them through recycling. It is important that the recycling method is selected so that the value of the recycled material remains as high as possible. The sorting of textile waste plays an important role when creating value added materials from the waste stream.

Non-reusable textiles can be divided into different material levels, which requires different recycling methods, Figure 20. In the mechanical recycling, textiles are opened back to fibres. The material can also be recycled as a polymer. Thermoplastic man-made fibres, such as polyester and polyamide, can be thermally recycled, and non-fusible natural fibres, such as cotton, chemically recycled. The thermoplastic synthetic fibres can be re-melted and processed to novel products by using various methods, by compression moulding, extrusion or casting. For example, 40 % of the recycled PET bottles are thermally converted to recycled polyester fibres. Thermal recycling of natural fibres is not possible because they do not melt, but they can be processed with the chemical methods into new fibres. In the chemical recycling of cotton, cellulose is dissolved and regenerated into man-made cellulose fibres. Textile waste can also be recycled as a monomer either as a raw material for a new polymer or as a raw material for new chemicals. If there is no appropriate recycling method for a non-reusable textile, it can be thermally converted into chemicals or utilized as energy. The different recycling processes can be combined, and often the different processes start with a mechanical process of a sort. For example, for the chemical recycling of cotton, the cotton textiles are first mechanically ripped. The different recycling processes are reviewed in more detail in by Kamppuri *et al.* (2019a).

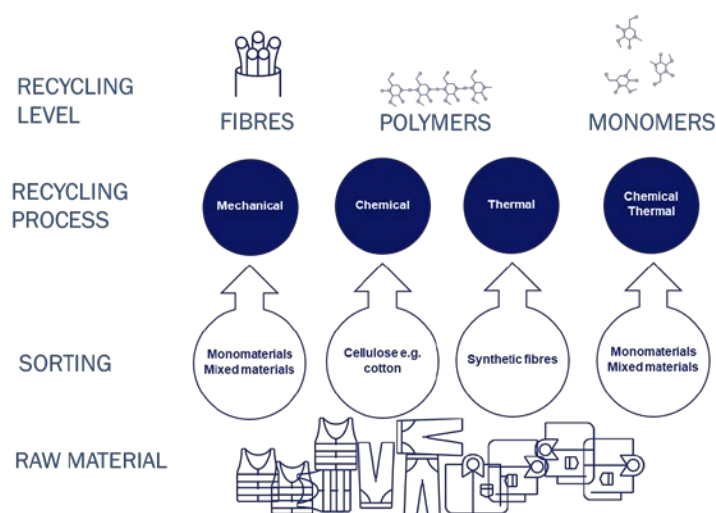


Figure 20 Different recycling processes for textile waste

The recycling method has an effect on the quality and properties of the recycled material. During the mechanical recycling, the decrease in the fibre length is the limiting factor for the further processing of the recycled material. However, for the natural fibres it is the only option if the fibre is to remain the same material, for example cotton remain cotton. To avoid the inevitable reduction of the quality of the natural fibres, the chemical recycling methods have been developed. For example, cotton is suitable raw material for the production of man-made cellulose fibres. For the synthetic man-made fibres, thermal



recycling is possible, but the thermal processing impairs the properties of the polymer and it is likely that the recycling cycles are limited, for example to 6-8 cycles, like in DutchAwareness<sup>21</sup>. The chemical recycling at the monomeric level is more expensive than the thermal recycling, but the quality of the fibres obtained from repolymerisation is equal to virgin one. The effect of the recycling method on the properties of different fibre materials are collected to Table 8.

*Table 8 Effect of recycling method on the quality of the processes material*

Fibre material	Effect of the recycling method on quality
Polyester	<p>Thermal recycling at polymeric level: weakens the quality of the polymer, purity of the material has a significant effect, recyclable 6-8 times.</p> <p>Chemical recycling in monomeric level: quality of the end product is equal to fibres from virgin polymer. It is still unknown whether the amount of recycling cycles is limited. A more expensive process than the thermal recycling.</p>
Cotton	<p>Mechanical recycling at fibre level: length of the fibres decreases, which may limit the further processing possibilities. The only possible process where cotton remains as cotton.</p> <p>Chemical recycling at polymeric level: cotton is converted to man-made cellulose fibres by the dissolution and regeneration. Quality of the end product is equal to fibres from virgin material (usually virgin wood cellulose).</p>
Polyamide	<p>Chemical recycling at monomeric level: quality of the end product is equal to fibres from virgin polymer. It is still unknown whether the amount of recycling cycles is limited.</p>
Wool	<p>Mechanical recycling at fibre level: length of the fibres decreases, which may limit the further processing possibilities. The only possible process where wool remains as wool.</p>

The largest material fraction obtained from recyclable textile waste was cotton. Its share has been varying from 30 % to almost 60 % (Kamppuri *et al.* 2019a), which is due to the normal variation in the collected waste stream and probably also due to the instructions given to the manual sorters. The mechanical and chemical recycling methods are available for cotton. In mechanical recycling, cotton remains cotton, but its fibre length is shortened, which limits its potential for further exploitation. If materials are sorted also according to its textile structure – for example knitted materials separated from woven, which require more processing to be opened – fibre length is not so much affected. The sorting according to colour is also possible and it reduces the need for dyeing of the final product. The mechanically opened cotton fibres are suited for yarn spinning and nonwovens, as the demonstrations in the Telaketju Tekes project have shown. In addition, the short dust fibre fraction, side-streams from mechanical opening and recycling processes, is suited for the foam laying (Chapter 5.2.5). Accurately sorted cotton is suitable raw material for the production of man-made cellulose fibres, whose fibre properties are comparable to the virgin man-made cellulose fibres.

The second largest recyclable fraction in textile waste was blends of cotton and polyester, and other blended materials (Kamppuri *et al.*, 2019a). The proportion of blended materials in the collected waste was 30-50 % and the share of cotton-polyester blends was about the half of that. The blended materials are suited for mechanical recycling. However, it is challenging to find an end use for such mixed fibres. There are applications where mixed fibres can be used, but usually the mixing is carried out so that pure fibre fractions are mixed with the desired shares. For example, in the demonstrations in the Telaketju Tekes project, the felt materials made of recycled fibres were a mix of natural fibres and synthetic fibres, which enabled the thermal bonding of the felts (more details e.g. in Chapter 5.3.2). It may be possible to use textiles from blended fibre materials as raw material for such applications.

The third large fraction in textile waste was polyester (Kamppuri *et al.*, 2019a). Although the world's fibre production is dominated by polyester, its uses are mainly in the technical textiles. The share of

<sup>21</sup> <http://dutchawareness.com/>



polyester in the post-consumer textile waste was thus less than 10 %. Polyester is suitable for mechanical recycling, which, however, shortens the fibre length and turns filament fibres into staple fibres. Theoretically, thermal recycling of post-consumer polyester textiles is possible, but in practice, the heterogeneity of the material at the polymer level complicates the thermal processing back to fibres. Today, 7 % of the world's fibre production is already recycled polyester. However, recycled polyester is often made of plastic bottles, which are more homogeneous at the polymer level than post-consumer textiles. Polyester can be recycled also at the monomeric level by chemical means. In the chemical recycling of polyester, the polymer chain is depolymerised into monomers that are suitable for re-polymerisation of polyester or as a raw material for other chemicals. Additionally, the chemical recycling of polyamide at a monomer level is possible. However, the proportion of pure polyamide is very low in post-consumer textile waste, so the availability of the raw material for the chemical recycling is more dependent on the availability of the technical textiles.

#### 4.5 Modelling of Costs

The purpose of the cost modelling was to estimate the costs of end-of-life textile recycling and compare the alternative end-of-life textile recycling scenarios in Finland. Assumptions and estimated costs were based on literature review, Telaketju expert interviews, literature and workshops. The purpose of the cost model created during the research is to get an estimation of the costs per one kilogram of recycled fibres in Finland: collected, sorted and recycled into fibres suitable for further processing into products.

Optimally re-usable and recyclable materials should be kept apart in collecting (Figure 21). Charity organizations could collect the reusable textiles and regional municipal waste management organizations the end-of-life textiles. This is challenging since most consumers do not have the expertise to categorise their clothes into reusable clothes and non-reusable clothes.

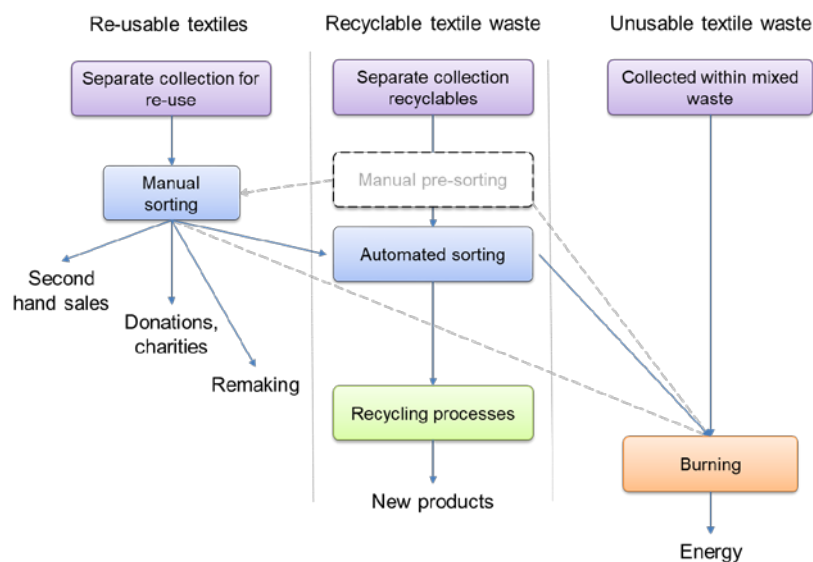


Figure 21 Possibilities in textile collecting and sorting (Re-drawn from Hinkka et al., 2019)

Regional handling centre can either sort the collected textiles or transport them to centralized handling. The benefits of the local handling are the reduced need for transportation and the local availability of sorted raw material. The challenges of this alternative are that because textile volumes are small, manual sorting might be the only alternative if investments in automation are not economically justified. The benefit of the centralized handling is the bigger material volumes that make investments in automation economically more feasible. On the other hand, the transport costs would be higher. Generally, Telaketju experts favoured centralized sorting, which makes automation economically viable. However, charity organizations could manually pre-sort textiles at regional sorting centres by separating out reusable

clothes and materials unsuitable for recycling. If the quantity of reusable clothes is reasonable, their value will offset the costs of pre-sorting.

The costs of centralized sorting vary widely depending on the sorting methods and technologies used, if sorting is fully manual, automatic-assisted sorting, or fully automated. The most cost-efficient way to handle sorting would be to use automation as much as possible, however, these technologies are still in development stage.

Modelled recycling options include mechanical recycling and chemical recycling via dissolution method, suitable for cotton. Other treatments needed and affecting the costs also included removal of components, such as zips and buttons, cutting of textiles into pieces and opening of fibres in for mechanical recycling fibres. The textile material may need washing for mechanical recycling, while chemical treatment allows the use of mixed and somewhat dirty materials. Washing is not included into calculations.

This cost model has several uncertainties, but based on the research, the following assumptions and estimations based on these assumptions were made:

- Total amount of end-of-life textiles available for recycling is 71,000 tons, i.e. 10.6 kg per capita.
- One collection point per 10,000 inhabitants will enable collection of 40 % of that → annual collection costs of around two million euros.
- Number of the local handling centres is equivalent to the number of administrative regions in Finland (18) → annual costs one million euros including the costs of pre-sorting. About 20 % of the collected material will be removed during pre-sorting.
- Centralized sorting is situated in Turku → transport costs around 300,000 €
- Annual costs of automated sorting would be around two million euros, while manual sorting would cost around 4.5 million euros annually.
- As the investment costs of treatment equipment are high, especially the chemical recycling process should be running round-the-clock. To enable better comparison of different recycling methods, also mechanical recycling is modelled to run round-the-clock.

Based on these assumptions, the total costs of collection and sorting would be 5.3 million euros annually meaning 0.43 €/kg. Recycling processes themselves were the most expensive phase of whole process. Mechanical treatment consisting of removing components, tearing and carding, would lead costs of fibres would be around 0.5-0.6 €/kg, and with chemical recycling, the costs of new fibres is 0.85 €/kg.

Based on this work, it seems possible to produce recycled textile raw material at a reasonable cost; at 1.0 €/kg if mechanical recycling is used and at 1.3 €/kg if chemical recycling is used. These costs are lower than the world market prices of cotton and polyester. However, achieving this requires the latest automation technologies and willingness of the consumers to separate out their old textiles and take them to collection containers. Furthermore, the presented estimated costs for the recycled textile material are based on certain simplifications. Main simplification is that the modelling assumes that all the material will be recycled by using either mechanical or chemical treatment. In practice, chemical recycling technology is suitable for cotton only and other natural materials, but not for synthetic materials. Therefore, both chemical and mechanical recycling are needed and thus, these price estimated are not accurate, but mainly directional.

## 4.6 Risks Related to Recycling

### 4.6.1 Risk Management

Textile recycling is in a phase of strong development. This development will also induce new emerging risks. Concerning emerging risks, it is essential to find out: a) what is known about the risks, b) is the

existing knowledge and its quality sufficient, and c) what kind of additional information should be gathered for managing risks. As long as knowledge is not sufficient, the worst possible consequences should be prepared for.

Risks are always related to the specific objectives of an activity, in this case textile recycling objectives. These objectives may be functionality, profitability, social acceptance, ecological aspects, and societal interests. This means, for example, that if the activity is expected to be profitable, everything that might threaten profitability is a risk. Also, if the activity is expected to diminish CO<sub>2</sub> emissions, everything that might threaten this objective is a risk. Functionality means simply that systems and equipment are expected to operate in a certain way. Risks threatening the life or health of people as well as social responsibility and public image are included in the category of social acceptance. Societal interests are mostly determined by regulation but also by different actions and statements of the public sector.

Different objectives may be contradictory in the sense that activities ensuring certain objectives may threaten other objectives. For example, environmentally good solutions may be more expensive and thus may threaten profitability. On the other hand, environmentally good but more expensive solutions may enable more revenue and profitability. Risk management means thus balancing these different objectives and taking into account the uncertainty related inevitably to the future.

Risk management aims to anticipate the challenges on the way to the objectives, and to manage overcoming these challenges. Identification of risks means building risk scenarios, that is, chains of events leading to unwanted consequences (Figure 22). The basic question is: ‘What could make the operation to deviate from the planned?’ An example of a simple risk scenario is as follows:

- *Unwanted event:* Trash in a textile collection container.
- *Contributing factors:* A container may be mixed up with a trash container; Pure mistake; Ignorance; Indifference.
- *Consequences:* Hinders sorting; Spoils textiles; Health risk; Spoils the final recycled product.
- *Risk management actions:* Control when receiving textiles; Guidance; Protective equipment for textile handlers; More robust recycling processes tolerating some trash.

Appropriate identification of risks requires good knowledge and understanding of the features, operation, behaviour and environment of the risk analysis object. The better the solution for a challenge is known the smaller is the risk in development work. In principle, it is recommended to eliminate the contributing factors (causes) rather than mitigating the consequences. However, if the elimination is not possible, multiple risk control arrangements may be needed. If multiple risks can be handled with the same mitigation arrangement, it may be more effective than trying to affect several contributing factors. And, if one can remove the causes of the risk, it usually is better than mitigation of the consequences.

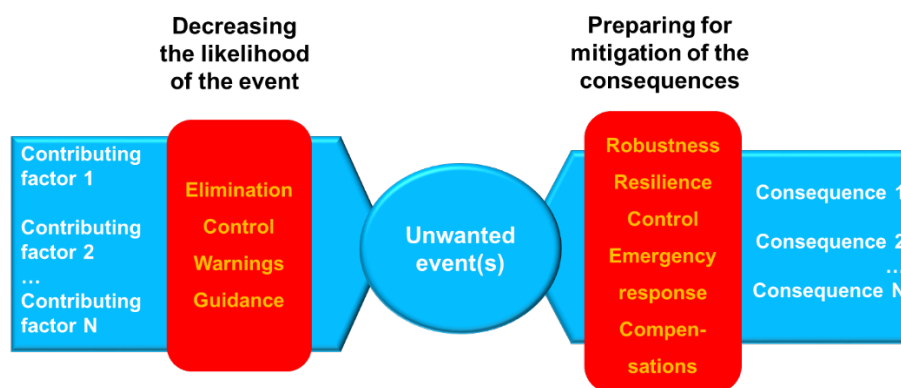


Figure 22 Risk scenario model, where several contributing factors together cause several consequences via a set of events (modified from Heikkilä & Heikkilä, 2018)

Risk management is actually an inherent part of developing anything new. It is commonly believed that risk management means always risk minimization. This is true only when the potential consequences are especially severe, if they are, for example, fatal. Otherwise, risks and benefits may be weighed and optimal balance should be searched for, and also regarding the costs of risk reduction.

The quantity of risk is traditionally defined as the function (typically sum or product) of the likelihood and the severity of potential consequences. Both could be estimated by different scales (Figure 23). The likelihood may be categorised, for example, as either *unlikely*, *possible* or *likely*. It may also be possible to estimate the number of times the risk is likely to appear during a certain period, for example, *about once a year*. However, the likelihood of a risk can be assessed only if the examined activities and environment related to the risk will remain the same and if there is enough information about earlier realized similar risks. For example, the likelihood of a certain traffic accident at a national level may be predicted with certain accuracy on the basis of the statistics from previous years. However, such statistics does not exist in most risk assessment cases. Therefore, there are no grounds for estimating the likelihood, and the severity of the potential consequences will be a determining factor in the risk assessment in such cases.

The severity of the potential consequences may be categorised as, for example, either *minor*, *harmful*, or *severe*. Severity is related to the objectives as presented above. If *functionality risks* (i.e. reliability) are examined, severity may be assessed as the time when the system will be not operating. Safety risks may be assessed as the number of injured or fatalities, and economical risks may be assessed as the value of the potential losses.

Risk (potential)	Severity of consequences			
Likelihood	minor	harmful	severe	unknown
unlikely	2	3	4	(4)
possible	3	4	5	(5)
likely	4	5	6	(6)
unknown	(4)	(5)	(6)	(6)

Figure 23 An example of a risk matrix to be used for assessment of risk levels. The numbers represent risk levels (Lanne & Heikkilä, 2016)

When the likelihood of a risk cannot be sufficiently assessed, the severity estimation will determine the further actions. If the severity is high (especially in the cases of fatality or catastrophic economic losses), a cautious implementation is required with all possible protections until enough information is gathered to confirm the sufficiency of safety. When the severity is lower, the requirement is not as strict. However, it should be noticed that the lack of information affects also severity assessments, and lack of information always means a higher risk (Figure 23).

Other categorizations were developed for the textile recycling risk assessment case in the project. The categorizations are presented here as an example: *Significance*, *criticality* and *controllability* of each risk were assessed without separately assessing the likelihood and severity of the risk. The significance of a risk had five categories: *operation ends totally*, *operation stops for a significant period*, *causes significant harm in previous or next phase*, *significant economic loss*, and *significant effect on reputation*. The criticality of a risk was classified as *critical*, *relevant*, or *negligible*. The controllability classes were *risk management solution is not known*, *risk is controllable but not easily*, and *easily controllable*.

#### 4.6.2 Challenges in Building a Textile Recycling System

The risks and challenges related to textile recycling have been reviewed in the project in order to aid the newcomers on the field. Technical solutions and processing capacity for the different phases of textile

recycling are widely developed at the moment. People are more and more aware and willing to bring their old textiles for recycling. However, the demand for recycled materials has not increased accordingly. Establishment of wide commercial demand for recycled materials in the industry and market is thus essential for the future of textile recycling. The aspects affecting demand are competitiveness and image. Competitiveness consists of quality, availability, price, and possible public measures of support recycled materials. Image also affects competitiveness. The significance of image is based on, how people value, for example, purity, chemical control, true environmental effects, familiarity of recycled materials, and how much they trust in the information given on these aspects.

Integration of different players and interests to form a well-functioning system is another significant challenge. The current and potential actors related to recycling are the various public, commercial and third sector organisations of different sizes as well as individual persons.

Concerning the technical challenges, the development of effective and reliable (automatic) sorting equipment for recyclable textiles seems to be one key issue. A partial solution to this challenge may be to lessen the requirements for sorting by developing more robust recycling processes and uses that can utilise more heterogeneous recycled textiles.

Textile recycling has several phases and players. They form an ecosystem in which everything affects everything. Thus, the significant challenges are eventually common challenges for everybody in the ecosystem. If any key player concentrates blindly and in the short run only on to maximize their own profit, it may endanger the functionality of the whole system in this phase.

## 4.7 Safety Issues Related to Textile Recycling

### 4.7.1 Chemicals in Waste Textile

In textile manufacturing, many different kinds of chemicals are in use. Some 10 % of them were considered to be a risk for human health, and round 5 % for the environment. (Swedish Chemicals Agency, 2014) These chemicals include substances that are carcinogenic, toxic for reproduction and sensitizing (allergenic). Such substances must be avoided in articles intended to direct and long skin contact. Substances hazardous for the environment are often persistent and/or bioaccumulating. For these reasons, several restrictions on chemicals, also on those of textile products, are defined in various global, EU or national regulations. All of them aim to eliminate or restrict the production and use of harmful chemical substances. Persistent organic pollutants (POP) are globally regulated and their use is prohibited or tightly restricted by Stockholm Convention, which obligations are included in EU Regulation EC 850/2004 binding all EU Member States. In the EU, the use of chemicals is controlled by the REACH Regulation, which includes listings of substances that need authorization or are restricted. Prohibited and restricted chemical substances were discussed in more detail within Kamppuri *et al.* (2019a).

In Finland, restricted and forbidden chemical substances are detected regularly in textile products in the routine spot checks performed by Customs. These include, for example, formaldehyde, prohibited aromatic amines and chromium VI compounds. However, during last years, only 2-5 % of the items tested have been illegal (Viljakainen, 2016; Tulli, 2017). Based on this, most of the post-consumer waste textiles seem to be safe, but the unknown history of waste textile may weaken the safety.

The probability that a textile contains certain harmful chemicals varies with the product type. During sorting, clearly dirty textiles can be sorted out, but if their contamination is invisible or odourless, it is impossible to detect it using only senses. One possibility to ensure the quality and purity of waste textile is to use different kinds of analytical techniques. At the moment, the suitability and efficiency of certain on-line analytical techniques are studied intensively.



Textile waste collected from consumers is quite heterogeneous. Typically, it contains different kinds of clothes; underwear and outerwear, and home textiles like curtains, bedspread and towels. In principle, all the textiles collected from consumers can be considered to be safe and suitable for their intended use, unless they have been contaminated with harmful substances during or after their primary usage. However, certain textile products such as children's and/or skin contact products are subject to requirements, which may restrict the use of recycled materials to produce them. In the textiles intended to a direct skin contact, some chemical substances (e.g. lead chromate containing dyes) are forbidden, and several (e.g. formaldehyde, particular azo dyes, Cr (VI) compounds, perfluoro octanic acid (PFOA)) are restricted. This may restrict the further use of waste textile, especially when mechanical recycling is applied. When the textile products made of waste textile will be in a direct and long skin contact or they are made for children, compliance of the products for these sensitive usages is recommended to ensure before placing them into the market.

Textile batches collected from companies are more homogenous in their composition compared to those collected from consumers. In addition, the detailed composition of the textile products as well the history of the waste textile are potentially known. However, some issues may restrict the further utilization of the textile waste. Textiles intended, for example, to public facilities are typically treated with flame retardants. In addition, working clothes are often flame-proofed. The fire retardant treatment can be persistent or may disappear during wear and tear or during washing cycles. If a persistent treatment is applied to textile products, whose lifetime is long, such as to curtains, they may contain also substances forbidden or restricted nowadays.

#### 4.7.2 Occupational Safety in Textile Recycling

People may be exposed to harmful chemical compounds existing in the textile products via skin and by inhaling and swallowing textile dust. If the material to be processed contains skin or eye irritating substances or sensitizers, exposure via unprotected skin and eyes is possible. If textile dust is not properly managed during processing, it may cause an occupational health risk. For organic dust, like textile dust, an occupational hygiene limit for two exposures times, i.e. 15 minutes and 8 hours, are given by Ministry of Social Affairs and Health (STM, 2018). The most potential process steps during which a lot of dust formation may occur in a mechanical recycling process are shown in Figure 24. During these steps, the exposure of workers to harmful chemicals and microbes, for example, moulds and spores, existing in the dust, is possible, too, if the dust management is not sufficient.

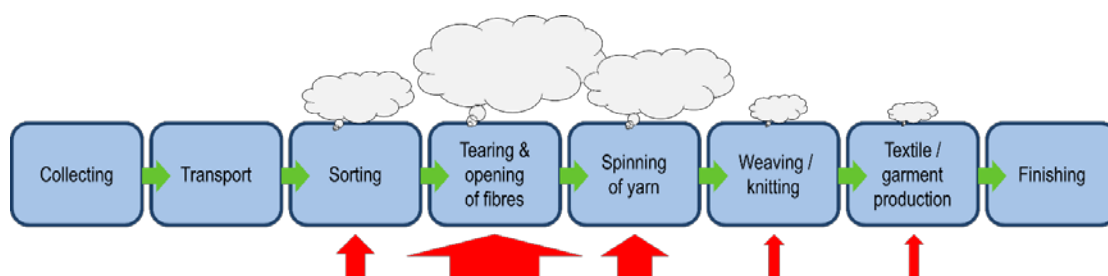


Figure 24 A mechanical textile recycling process from discarded textiles to new textile products. The process steps during which dust formation may most probably need additional risk management measures are marked with red arrows (Pitkänen et al., 2018)

#### 4.7.3 Dust Formation in Spinning Yarn from Mechanically Recycled Cotton

Mechanical recycling, in which the textile structure is disintegrated back to cotton fibres, decreases the length of fibres and may decrease the strength of them. These changes increase the probability of dust formation in further processing. Therefore, the formation of airborne dust from mechanically recycled cotton during ring spinning was studied in more detail. It is known that cotton dust is harmful to health when breathing, but it is unknown whether the processing of mechanically recycled cotton fibres has a

higher tendency to dust formation and thus to increase health risks. The objective was to study the formation of airborne dust from mechanically recycled cotton during carding and ring spinning of yarn. The formation of dust from the recycled cotton was compared to that of virgin cotton. An overview of the materials and methods is given in Chapter 5.2.2.

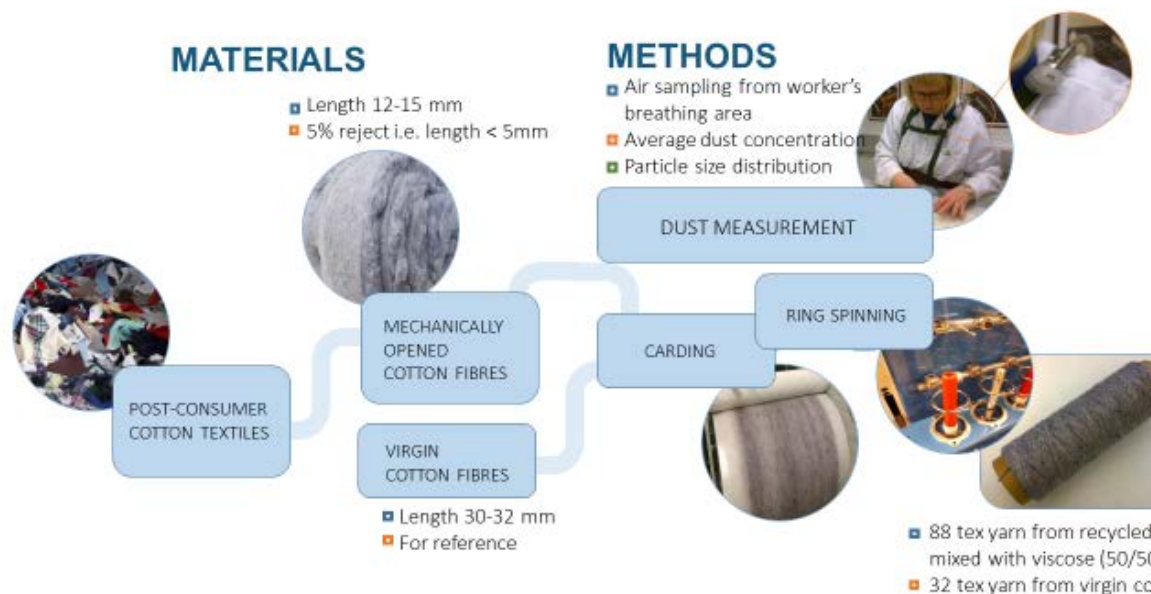


Figure 25 An overview of the materials and methods. The formation of dust was measured during carding and ring spinning (Kamppuri et al., 2018)

Airborne dust consists of particles that float in the air. The average dust concentration in the air was measured during carding and ring spinning from a worker's breathing area so that the collecting filter was attached to the worker with a harness shown in Figure 25. The average dust concentration was measured by collecting the dust on a filter by sucking air through it with a pump and then by weighing the filter. In addition to airborne dust, the recycled cotton fibres created fibre fragments that settled on the floor surfaces.

The amount of airborne dust in the workplace's air was measured during processing both virgin and mechanically recycled cotton, and the results were compared to concentrations known to be harmful to humans. In both cases the amounts of airborne dust were low compared to the limit given for occupational exposure during a working day ( $5 \text{ mg/m}^3$ , 8 h). However, the average dust concentration of the mechanically recycled cotton was higher during carding, which indicates that the recycled cotton fibres were broken during carding. During yarn spinning, the average dust concentration was clearly lower than during carding and was at the same level in the both studied cases (Figure 26).

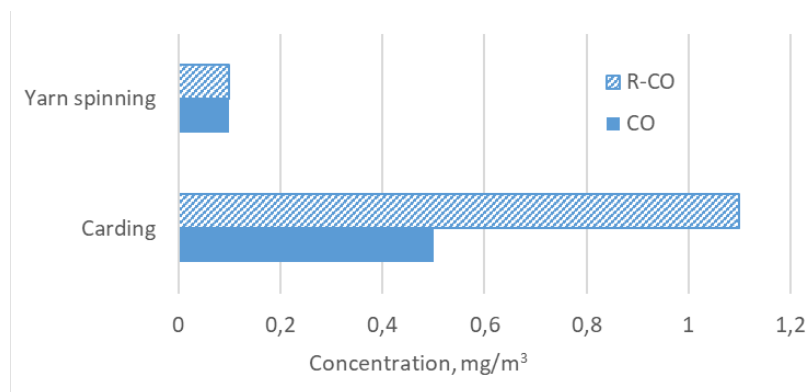


Figure 26 Average dust concentrations in the air during the carding and yarn spinning of virgin cotton (CO) and recycled cotton (R-CO) (Kamppuri et al., 2018)

Additionally, the particle size distribution of the airborne dust was studied with a cascade impactor method that classifies the particles according to the aerodynamic particle size. During carding of the recycled cotton fibres generated more dust and especially larger dust particles than that of virgin cotton fibres. During the yarn spinning, the airborne dust concentration from both the recycled and virgin cotton fibres was much lower than during the carding. This result could be due to the smaller amount of fibre materials handled, and existence of a local exhaust ventilation in the spinning apparatus applied. Because of the low concentrations, it was irrelevant to make any conclusions of the results between virgin and recycled cotton during the yarn spinning.

In conclusion, during the carding mechanically recycled cotton fibres created over 50 % more dust than virgin cotton. However, there was not a clear difference between virgin and recycled cotton in dust formation during ring spinning. In this study, all the measured dust levels were under the exposure limits laid down for organic dust. However, dust is formed during processing and it is vital to take precautions to minimize the possible occupational health risks. (Kamppuri *et al.*, 2018)

#### 4.7.4 Dust Formation in Foam Laying from Mechanically Recycled Cotton

Foam laying technology (described in Chapter 5.2.5) can be applied to fibre fractions originating from mechanical recycling processes. By using foam laying technology also very short fibres, commonly considered as waste, may be used as a raw material and be processed to new textile products. Because mechanical disintegration decreases the length of fibres, the possibility of dust formation in further processing will increase.

In the foam laying process, both mechanically recycled cotton fibres and cotton dust released during mechanical recycling (Figure 27) were used as a raw material. The dust concentration was measured from the work place's air and from a worker's breathing area. Like in the case of the carding and ring spinning, the average dust concentration was measured by collecting the dust on a filter by sucking air through it and then by weighing the filter, and the particle size distribution of the airborne dust was measured with a cascade impactor method. The dust concentration in a worker's breathing area was determined by attaching the collecting filter on the worker's shoulder. In addition to a personal filter sample, the dust concentration was measured in two fixed measuring points placed in a central position of the research hall and in the testing laboratory.



Figure 27 a) Cotton dust obtained as a waste fraction from mechanical recycling, and b) mechanical recycled cotton fibres

The amounts of airborne dust in the workplace's air were measured during the following stages of the operation: 1) tearing the mechanically processed fibres apart; 2) weighing the raw material portions; 3) adding the raw material into the foam laying process; and 4) during handling the foam laid nonwoven samples. During tearing the dust concentrations measured were low compared to the limits given for 8 hours and for 15 minutes exposures specified for textile and other organic dusts. During weighing the cotton dust and adding it into the foam laying process, the occupational limit given for 15 min exposure

exceeded. The particle size distribution of the cotton dust collected during these stages of operations showed that about 25 % of the airborne dust consisted of particles with a diameter below 4  $\mu\text{m}$ . These tiny particles could be harmful for health because they can end up into the pulmonary alveoli area situated deep in the lungs.

In addition, airborne dust with a diameter below 5  $\mu\text{m}$  tends to float in the air and, thus, it can be carried by air flows a long way. Therefore, in this case applicable risk management measures should be considered in order to prevent, or at least minimize, the formation and spreading of the airborne dust into the working area's air. The amounts of airborne dust in the workplace air during handling foam laid textile fibre samples can be compared to the occupational limit given for 8 hour exposure specified for textile and other organic dusts. The measured concentration was very low compared to the limit. During the pilot trial, an optical measuring method to measure number of airborne particles in the working space's air was employed, too. The results obtained from the direct measurement were in line with the results obtained with the filter method.

#### 4.7.5 VOC in Foam Laying and Handling Foam Layered Materials

The amount of volatile organic compounds (VOC) in the workplace's air was analysed using the gas chromatography (GC/MS) method and the results were compared to the occupational limit values laid down by STM. The determined concentrations were much lower than the limit values known to be harmful for human health, except benzaldehyde and benzyl alcohol, which concentrations were significant, however the corresponding occupational limits did not exceed. In this case, their sources remained unknown. The determined total VOC concentrations (TVOC) 40-60  $\mu\text{g}/\text{m}^3$  were low compared to the target level specified for industrial air quality (300  $\mu\text{g}/\text{m}^3$ ). By comparison, the reference value for industrial air quality that requires preventing risk managing measures is 3000  $\mu\text{g}/\text{m}^3$  (Tuomi *et al.*, 2012).

In addition, some volatile compounds for which occupational limit values have not been specified were detected in air samples, too. These compounds were, for example, 1-dodecanol, an impurity and decomposition product of the surfactant applied in processing, some aldehydes, and some traces of aliphatic and aromatic hydrocarbons. According to International Chemical Safety Cards (ICSC) database, the health effects due to exposure to the 1-dodecanol have not yet been investigated adequately, although it is supposed to be irritating to the skin, eyes and respiratory tract (ICSC database, 2018).

#### 4.7.6 Surfactant Concentration in Airborne Dust

In the foam laying processing, chemical substances to produce a strong and long-lasting foam are needed. These substances, generally called surfactants, are familiar from soaps, shampoos, washing powders, detergents and other cleaning products used in households. Different surfactants have different kinds of properties, and thus they may affect, for example, skin, eyes and airways differently in terms of irritation. Therefore, the airborne spreading of surfactants used in foam laying processes was studied in more detail during the pilot trial.

The dust deposited on the collecting filters were extracted and the amounts of the surfactants in the extracts were analysed using a method described by Kamppuri *et al.* (2019b). The results showed that the dust deposited on the collecting filters contained different amounts of surfactants, and that the highest concentrations were about 100 mg/g. Because common laundry detergents contain same kinds of surfactants as were used in the foam laying, also the initial concentrations of the surfactants in both test materials, mechanically processed cotton fibres and cotton dust, were measured. The cotton dust was post-consumer origin, and the mechanically processed cotton fibres were pre-consumer origin. The concentration of the surfactants was higher in the cotton dust released during mechanical recycling (about 3 mg/kg) than in the mechanically recycled cotton fibres (0.7 mg/kg).



The differences in the surfactant concentration between the deposited dust collected from the workplace's air, original textile dust and textile fibre indicate that there is an additional source of surfactants in the working environment. The highest concentrations in deposited dust were measured when the dust content in the air was low and the long measuring time allowed large amounts of air to flow through the collecting filter during sampling. There is no occupational limit for surfactants. Depending on the nature of the surfactants (i.e. whether they are cationic, anionic, zwitterionic or non-ionic surfactants), they may cause health effects with different intensities. Therefore, it is important to take precautions to minimize the possible risks.

#### 4.8 Regulation Related to Textile Recycling

Regulation and terminology work was led by Telaketju YM project, but was carried out in co-operation with Telaketju Tekes project. Based on a workshop and interviews of several specialists, the Senior coordinator Hanna Salmenperä (SYKE) collected a report that puts forward a proposal for the key terms related to textile waste (Salmenperä, 2017). The report also comprehends the administrative procedures for the collection and sorting of textile waste. The report contains also information about the current sharing of responsibility related to textile waste. This model was also compared to two alternative models that could possibly be applied in the future:

1. The producers of the textiles are responsible for textile waste, or
2. Sharing of responsibility is determined in a voluntary deal between the key players, such as municipalities and textile producers).

Guidelines for the exporters of used textiles and textile waste were drafted from the point of view of the international waste shipment legislation. The main terms of waste legislation related to textile waste and the cases when waste legislation and a notification procedure are applied are shown in Figure 28 and Figure 29, respectively.

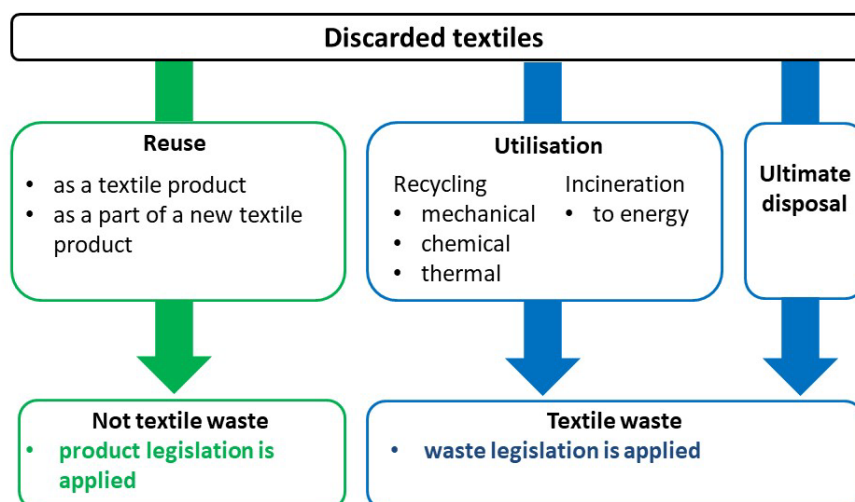


Figure 28 Terms in waste legislation related to textile waste and the cases when waste legislation is applied to discarded textiles. Redrawn from Salmenperä (2017)



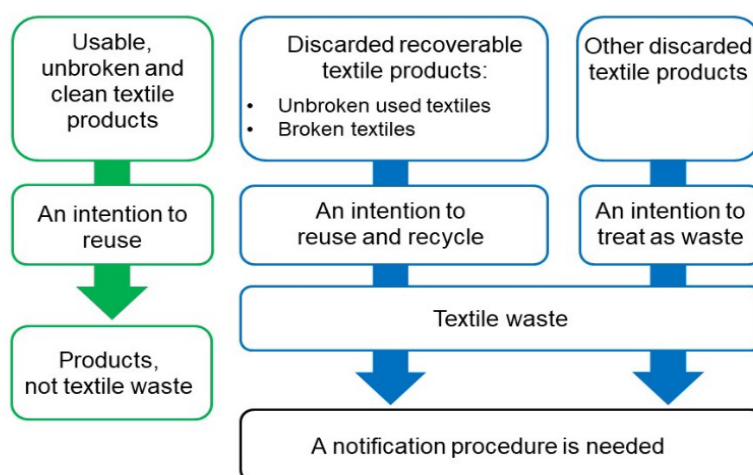


Figure 29 The conditions under which a notification procedure is applied. Redrawn from Salmenperä (2017)

#### 4.8.1 Current Changes in the Finnish Waste Act

The Finnish Waste Act is revised in two phases, which is based on the present government platform. In the first phase, the changes were directed at two subject areas: the sharing of responsibility concerning management of municipal waste and the market-based services provided by municipalities. These changes took effect on 1 January 2019. At the second phase of revision, an electric information platform for waste and side flows is built. This amendment is meant to take effect on 1 January 2020. (Act 445/2018; HE 195/2017; HE 248/2018;). In addition, the current and future EU-regulations will change the Finnish Waste Act in the near future. (Figure 30) The objectives associated with waste management and prevention in Finland are also highlighted in the *National waste plan* (Laaksonen *et al.*, 2018). It presents long-term objectives and measures for management and prevention of waste, such as municipal waste. In addition, the *Finnish plastic roadmap* (Ministry of Environment, 2018a) presents the key measures to solve the problems associated with plastics.

**Limited responsibility.** Due to the changes in the Waste Act, the responsibility of the municipalities to manage municipal waste is limited mainly to the waste produced through households and municipal administration and service activities. For other producers or owners of waste, municipalities will thus provide waste management services only as subsidiary liability service (TSV-service) or as market-based service. The objective of these limitations is, for example, to promote competition and business activities within the waste management sector. (Act 445/2018; HE 195/2017; Stén, 2018)

For textile waste, the above limitations mean that the municipalities will be responsible for the textile waste produced by households and municipal administration and service activities (excluding social and health services). The public sector, private social and health services, educational services as well as various private activities including trade sector, services and industry (textile waste similar to that produced through housing) are in charge of managing their own textile waste. (Salmenperä, 2017)

**Proportion of market-based services.** The market-based waste management services can account for at most 10 % of the municipal waste management services. This proportion will fall to 5 % in 2030. However, there will be no limit for the market-based services provided by municipalities in terms of money. The objectives of these changes are, for example, to open waste management markets, to secure equal possibilities for competition for public and private actors in the waste management sector and to secure reasonable availability of waste management services. (Act 445/2018; HE 195/2017)

**Some potential effects of the amendments.** It has been estimated that the amount of municipal waste managed by the municipalities will decrease by about 8 % due to the limited responsibility. This is equal to 8-12 % of the turnover of the municipal waste plants. The effect of these changes will probably be

minor on average but significant regionally. It is also possible that due to the limitations on the statutory and market-based waste management services of the municipalities the municipal waste management companies will merge. The effect of these changes on innovation activity within the waste management sector is probably small. (HE 195/2017) In addition, according to the Environment Committee of the Parliament of Finland, the effect of these changes on the promotion of circular economy (and textile recycling) is indirect, as they do not include any material regulation. In addition, the amount of the waste that is no more municipalities' responsibility is probably too small to promote investments in waste recycling or utilization plants. Limitation of the municipalities' responsibilities challenge thus other actors to fulfil recycling targets efficiently. (Environment Committee, 2018)

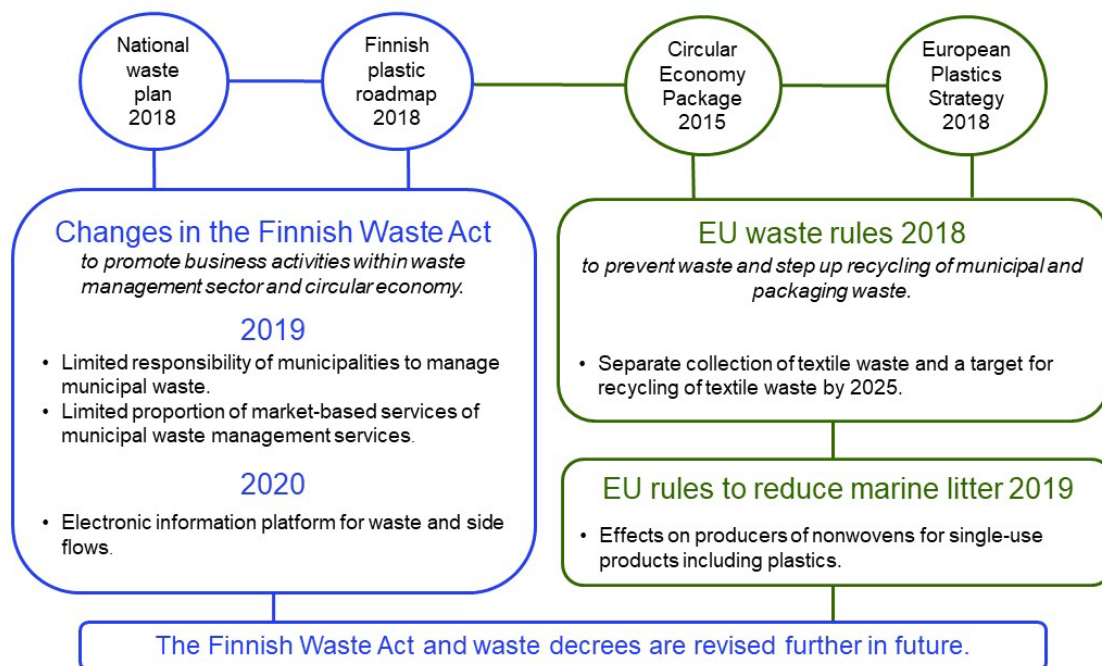


Figure 30 Current and future changes in Finnish and EU legislation with relation to waste management and prevention

**Professional electronic information platform for waste and side flows.** The markets of the waste sector will be developed through creating an electronic information platform for waste and side flows. The objective of the platform is to boost and develop the waste management and recycling sectors by helping the possessors of waste or side flows to find waste management services or other appropriate services (for example utilization of side flows). The waste management services are primarily found from the open market and secondarily as subsidiary liability service provided by municipalities. The platform aims at promoting circular economy, recycling markets and the demand for recycled materials and at helping the owner of waste to show their need for the subsidiary liability services of waste management transparently. Motiva Oy is the administrator of the platform. The platform was tested regionally early in the year 2019 and it was put into operation on a pilot scale in April 2019. (HE 248/2018; Materiaalitori, 2019; Ministry of Environment, 2018b) It has been estimated that the platform can promote innovations and investments concerning recycling and circular economy and development of new waste management solutions (HE 248/2018).

Some online platforms have been used for trading textile waste streams. Definition of the necessary information on the various textile materials and products to be traded online is, however, not an easy task. Information that could be beneficial for determining the quality and properties of various textile materials and textiles traded as a side stream or as waste are summarized in Table 9.

*Table 9 Information for determining quality and properties of textile materials accurately in electronic information platform for waste and side flows*

Textile type	Information concerning properties, quality and quantity of textile waste and/or side streams
All textile materials	<ul style="list-style-type: none"> <li>• Original <b>producer</b> and intended original <b>use</b></li> <li>• <b>General properties:</b> colour, raw material composition including mixing percentages of blended materials</li> <li>• <b>Background:</b> Pre-consumer waste / surplus material / post-consumer; age and storing type; use history information e.g. Chain of Custody; condition (e.g. good as new / worn / broken; clean / dirty including type of dirt and possible contaminants)</li> </ul>
Fibres	<ul style="list-style-type: none"> <li>• <b>Production method:</b> origin and production method for natural fibres, spinning process for man-made fibres, finishes and other treatments</li> <li>• <b>Properties:</b> Length and its variation, linear density (dtex)</li> <li>• <b>Form of material:</b> filament / staple fibre, loose fibres / fibre mat / bale etc.</li> <li>• <b>Quantity:</b> mass (kg, tonne), number of bales including bale size</li> </ul>
Yarns	<ul style="list-style-type: none"> <li>• Above mentioned fibre property and production methods information, if/when available and relevant for re-use, re-manufacture and/or recycling</li> <li>• <b>Production method:</b> Spinning method (ring, open-end), for synthetics is it filament or staple fibre yarn,</li> <li>• <b>Properties:</b> Yarn count, linear density (tex), twist and plying/cabling</li> <li>• <b>Form of material:</b> yarn cuttings, continues yarns including with length information, mixed / homogenous</li> <li>• <b>Quantity:</b> mass (kg, tonne), amount of cones including cone size</li> </ul>
Fabrics	<ul style="list-style-type: none"> <li>• Above mentioned yarn property and production methods information, if/when available and relevant for re-use, re-manufacture and/or recycling</li> <li>• <b>Production method:</b> <ul style="list-style-type: none"> <li>○ Woven, knitted, warp-knitted fabrics: process and used weave or knit</li> <li>○ Laces and braids: process and type</li> <li>○ Nonwovens: web formation method, bonding method and treatments</li> </ul> </li> <li>• <b>Finishing</b>, if included: dyeing and/or printing method(s) including colours and patterns, other finishing treatments (e.g. fire-retardant, anti-static, anti-microbial, dirt or liquid repellence), lamination and/or coating type (material and method)</li> <li>• <b>Properties:</b> Thickness, areal weight, tensile strength, stretch, stiffness, drape, softness, durability, breathability, permeability</li> <li>• <b>Standards</b> if applied (e.g. technical materials) and <b>limitations</b> of use (e.g. if contains chemical substances restricted in skin contact)</li> <li>• <b>Form of material:</b> cut pieces of fabric including with size information, mixed / homogenous</li> <li>• <b>Quantity</b> can be expressed by mass (kg, ton), length (m/km), amount of rolls including roll width, area (m<sup>2</sup>), amount of bales or other containers</li> </ul>
Clothing items and other products	<ul style="list-style-type: none"> <li>• Above mentioned fabric property and production methods information, if/when available and relevant for re-use, re-manufacture and/or recycling</li> <li>• <b>Type of product</b> (garment, home textile, technical product type), for clothing intended user (male / female / child), information about non-textile parts (zippers, buttons) if included</li> <li>• <b>Properties:</b> size, fit</li> <li>• <b>Standards</b> and ID tags if applied (e.g. products for children, work and protective clothing), limitations of use (e.g. authority uniforms, protected patterns)</li> <li>• <b>Form of products:</b> whole products or pieces of products, contain/not contain non-textile parts, mixed / homogenous</li> <li>• <b>Quantity</b> can be expressed by: mass (kg, ton), amount of pieces, amount of bales or other containers</li> </ul>

#### 4.8.2 Current and future EU-regulations

**The reforms of the waste rules.** The reform of the waste rules of the European Union (Directive (EU) 2018/851), which are based on the *Circular Economy package* (European Commission, 2015), will also step up recycling of waste by tightening the recycling targets for municipal and packaging waste. This will be overtaken by setting separate collection obligations for hazardous household waste (by 2022), bio-waste (by 2023) and textiles (by 2025). (European Commission, 2018b) The reforms took effect in July 2018 and they need to be implemented in the national legislation by July 2020 (Stén, 2018). In future, the European Commission also needs to investigate possibilities to set targets for, for example, recycling of textiles and reuse of packages. (Ministry of Environment, 2017). European Commission will consider setting targets for recycling of textile waste by the end of year 2024 at the latest (Directive (EU) 2018/851). In order to be able to implement these reforms in Finland, the Finnish Waste Act needs to be revised soon. In addition, the tightening waste rules increase the need for new recycling innovations and investments. (Environment Committee, 2018).

**New EU-wide rules to reduce marine litter.** In order to decrease the amount of plastic litter in oceans and seas, the European Commission has proposed new rules to target 10 single-use plastic products and lost and abandoned fishing gear. This initiative will put into practice the commitment made in the *European Plastics Strategy* (European Commission, 2018d) to tackle wasteful and damaging plastic litter through legislative action. In the strategy, a Cross Industry Agreement signed by five industry associations for the prevention of micro plastic release into the aquatic environment during the washing of synthetic textiles was set to develop first proposals on test methods in 2018. The Commission will consider measures such as better information and minimum requirements on the release of microfibers from textiles (European Commission, 2018d).

These new rules will affect producers of nonwovens for single-use products like wet wipes and hygiene products (sanitary towels) that include plastics. The rules will oblige producers to help cover the costs of waste management and clean-up (wet wipes) as well as of awareness raising measures. The industry will also be given incentives to develop less polluting alternatives for the products. In addition, the products will require a labelling including information on disposal, negative environmental impact and presence of plastics in the products. (European Commission, 2018c; Nikula, 2019) The European Parliament and the Council of the European Union have reached a provisional political agreement on the proposal in December 2018. The rules will be officially approved by the Parliament and the Council in the beginning of year 2019 and they will be published probably in early summer. The member states should to incorporate the new rules into their national legislation after two years. (European Commission, 2018e; Ministry of Environment, 2018c).

## 5. Trials and Demonstrations

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One main target of the Telaketju Tekes project was to test processes and demonstrate products made from a wide range of textile waste fractions and using a wide range of technologies and processes. The aim was to make trials and demonstrations on a lab and pilot scale as well as on an industrial scale in companies. We also wanted to model future value chains for making circular products.

The recycling demonstration carried out in co-operation with producer of mechanical recycling lines, Laroche<sup>22</sup> company, was an excellent example of co-operation that can be carried out in a large ecosystem such as Telaketju. It involved Telaketju YM and Tekes projects as well as research organizations and companies in handling, testing and processing of materials, thus, linking multiple demonstrations into a chain.

Trials and demonstrations are divided under following themes: product design (Chapter 5.1), mechanical recycling processes (Chapter 5.2), products from mechanically recycled fibres (Chapter 5.3), chemical recycling (Chapter 5.4), and thermal recycling (Chapter 5.5). Some of the demonstrations described here were results of company projects.

### 5.1 Product Design

#### 5.1.1 Creative Design Methods towards Circular Economy

The purpose of this assignment for Lahti University of Applied Sciences (Institute of Design) was to familiarise design students, i.e. future textile design specialists, with the principles of sustainable design towards a circular economy. The design theme was a kids' collection for winter. The target of the design process was to design garments that are easily recyclable either as apparels or as textile materials according to waste hierarchy. Special attention was paid, for example, to choosing either from monomaterials i.e. composing of only one type of fibres, or blends where the use of blend is justified. Many of the designed outfits contained parts that can be removed or replaced easily. Recycling plans for materials within this design assignment are shown in Figure 31.

In addition to increasing the design students' awareness of the issues affecting apparels' recyclability due to material choices, this design process exercise lead to a broader context. From now on, the textile samples that are at the students' disposal will consist mainly of single materials as well as of carefully selected blends of materials. This will increase the recyclability of the designed garments in the future, as the identification and sorting of them by their fibre contents will be easier.

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<sup>22</sup> <https://www.laroche.fr/en>



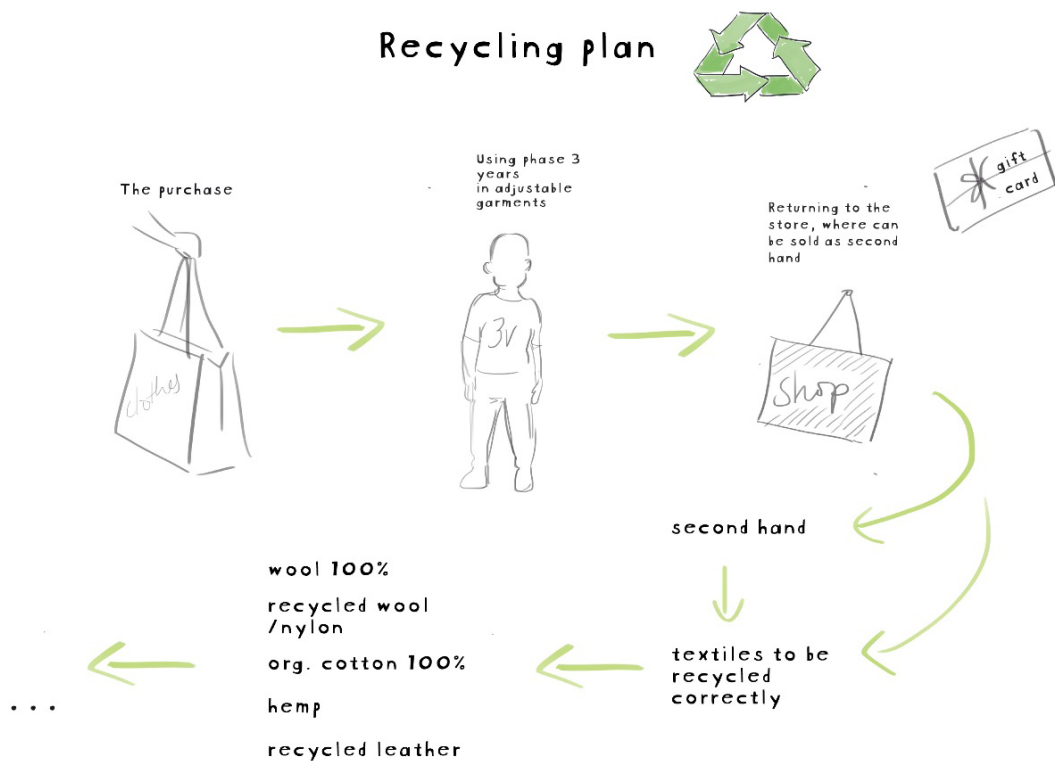


Figure 31 Recycling plans for materials and fabrics from Lahti University of Applied Sciences student design assignment

### 5.1.2 Ecological Work Wear for Caring Industry

Touchpoint is a producer of ecological work wear. In its pilot, Touchpoint produced prototypes for the collection of ecological work wear for caring industry called Heal (Hoiva) (Figure 32).

For the Heal collection, Touchpoint looked for new ecological materials that had not yet been used for work wear in caring industry. The clothes used in caring industry have to endure industrial washing and they have to be antibacterial and practical. The materials used to produce the work wear were, for example, recycled polyester and fabrics called Infinity<sup>23</sup> and Ecogreen<sup>24</sup>. Infinity can be recycled (clothes opened into fibres, fibres spun into yarns and yarns woven to fabric) up to eight times. Ecogreen is made of cellulose using the lyocell-method as well as of recycled polyester. The recycled polyester, which is made from pet bottles, has already been used as a textile material. Other materials used included Tencel-polyester mixture, organic cotton, fabrics with Bluesign<sup>25</sup> and Ecostep<sup>26</sup> certificates.

Materials of the Heal work wear circulate in a closed loop, as the worn out clothes can be utilized in the production of new clothes or as raw material for composites that are used, for example, for outdoor furniture. The service model for the recycling of work wear is under development. In addition, the design of the outdoor furniture needs to be developed further.



Figure 32 Materials of the Heal work wear circulate in a closed loop (Touchpoint)

## 5.2 Mechanical Recycling Demonstrations

### 5.2.1 Opening and Air-Laying of Recycled Materials

The objective of the project was to produce fibre-based materials from post-consumer textiles for demonstration purposes in pilot scale. Discarded cotton and polyester textiles collected by Lounais-Suomen Jätehuolto and sorted (material based sorting; knitted and woven fabrics sorted together) by Texvex workshop of Turun Seudun TST ry. The material collected and sorted consisted of discarded cotton (400 kg) and polyester (200 kg). Buttons, zippers and other hard parts were removed from the

<sup>23</sup> <https://www.steinfibers.com/environment/>

<sup>24</sup> [https://www.npc.com.tw/j2npc/enus/prod/Fibers/Spin-Draw-Yarn\(SDY\)/Recycle%20Polyester%20FDY](https://www.npc.com.tw/j2npc/enus/prod/Fibers/Spin-Draw-Yarn(SDY)/Recycle%20Polyester%20FDY)

<sup>25</sup> <https://www.bluesign.com/>

<sup>26</sup> <http://www.ecostep-online.de/>

materials in advance. The sorted material was sent to Laroche technical centre. The piloting days were organized by Ilmakunnas and the pilots were carried out at Laroche in France during 24-25.1.2018.

At Laroche's technical centre, the textiles were converted back to fibres by cutting and opening. Part of the fibres were mixed and made to nonwoven felt with air lay and needle punching and/or thermal activation. The course of the recycling demonstration is illustrated in Figure 33.



Figure 33 Demonstration of the mechanical recycling process at Laroche's technical centre. Process description by Pirita Hyrkkäinen, Lahti University of Applied Sciences

The materials of the nonwovens consisted of recycled cotton, recycled PET (polyester) as well as of industrial waste PP (polypropylene) (100 kg) and virgin bi-component PET (250 kg). Four formulas were manufactured from the opened fibres with air lay technology: three (3) thermoformable nonwovens containing 50-90 % recycled fibres (needle punched) and one isolating material containing 80 % recycled fibres. The basis weights of the air laid felts and mats ranged up to 3800 g/m<sup>2</sup>. Appearance sorted fabrics cut to pieces in two directions, opened fibres, and air-laid felt are shown in Figure 34.

Materials processed by Laroche pilots were sent to various Telaketju partners for testing and further processing. Opened fibres were tested in production of yarns by VTT (Chapter 5.2.2), for nonwovens by Suominen (Chapter 5.2.4) and VTT (Chapter 5.2.5), and package materials by Paptic (Chapter 5.2.6). Air-laid nonwovens and felts were used for production of acoustic panels by Soften (Chapter 5.3.2), back-bag padding by Globe Hope (Chapter 5.3.3), and as an alternative for cardboard in Art Immersion workshops by Turku University of Applied Sciences (Chapter 5.3.4).





Figure 34 a) Sorted fabrics cut to pieces in two directions at Laroche; b) opened fibres; and c) air-laid felt from recycled material suitable e.g. for isolating purposes

## 5.2.2 Ring Spinning of Mechanically Recycled Fibres

The suitability of mechanically recycled fibres from post-consumer textiles for ring spinning was demonstrated with materials obtained from Laroche demo (Chapter 5.2.1). The yarn spinning was subcontracted to Tampere University of Technology. The fibres were carded, drafted to slivers and combined to form a roving, and the yarns were spun by the ring spinning method. The mechanically recycled fibres consisted of recycled cotton and polyester.

The carding was possible with 100 % recycled fibres. However, the sliver formation and yarn spinning were not successful, which was likely due to the too short fibre. By adding longer virgin cotton or viscose fibres the yarn spinning was possible and the yarns were strong enough to withstand knitting (Figure 35). Both mechanically recycled cotton and polyester fibres were suitable for the yarn spinning. More detailed description of this demo is included as Annex 1.



Figure 35 a) Yarns from 50 % r-CO (6) / 50 % CV (virgin) and 50 % r-PET / 50 % CO (virgin) and b) yarn and knitted sample from 30 % r-CO (5) / 70 % CV (virgin)

### 5.2.3 Open End Spinning of Mechanically Recycled Fibres

In this demo, Pure Waste Textiles developed and tested mechanical recycling of pre-consumer and post-consumer textile waste (100 % cotton) to manufacture yarn for knitted and woven textiles. Within this demo, various equipment for the mechanical opening were tested of textile waste targeting to obtain spinnable fibres. The homogeneity of the textile waste was a challenge, because it determines the homogeneity of the opened fibres, too. That underlined the importance of a well-organized and performed collection, sorting and pre-treatment.

In addition, the spinning of various recycled fibres (100 % recycled cotton, mixed with recycled viscose and/or polyester) into yarn was tested, developed and carried out. The fibres were spun into yarn using open-end spinning and ring spinning. The aim was to be able to use post-consumer waste, without losing quality properties. Most promising test result was from yarn made of recycled fibres that consisted of post-consumer textile waste (20 %), pre-consumer textile waste (40 %) and recycled polyester (40 %) by open end spinning process.

The feasibility of the yarn for the production of different types of knitted and woven fabrics was also tested (Figure 36a). The objective was to produce fabric that meets the quality standards of Finlayson and Touchpoint. The high volume of yarn needed for weaving was a challenge in the weaving tests.

In addition to its own demo, Pure waste Textiles also supplied fibres from pre-consumer textile waste were also supplied to VTT (Chapter 5.2.5), Paptic (Chapter 5.2.6), and Soften (Chapter 5.3.2).



*Figure 36 a) T-shirt made of yarn that consisted recycled post-consumer textile waste (20 %), pre-consumer textile waste (40 %) and recycled polyester (40 %); b) Nonwoven prototypes made of recycled and bleached IFC fibres and polyester (upper samples) and recycled fibres from Laroche demo and polyester (lower samples)*

### 5.2.4 Carded Nonwovens Made of Post-Consumer Cotton Fibres

Suominen produced nonwoven prototypes from recycled materials on a pilot scale (Figure 36b). The recycled fibres were available from Telaketju partners and trials during the project. The company used its pilot lines in Nakkila, Finland for production of prototypes, where standard virgin fibres such as polyester and viscose were partly replaced by recycled fibres. The main target was to test the processability of recycled fibres and to find out the amount of recycled fibres that could be blended with virgin fibres without sacrificing the processability and the fibre web quality of the nonwovens.

Post-consumer cotton fibres, which were mechanically recycled and bleached (from Infinited Fibre Company), were used in a 50/50 blend with standard 1.7 dtex polyester (Figure 37a). In addition, 50 %



of the recycled unbleached fibres (Figure 37b) from Laroche demo (Chapter 5.2.1) were blended with standard polyester to produce nonwoven samples. The basis weight of the nonwoven sheets ranged from 45 to 50 g/m<sup>2</sup>. The manufacturing technology included carding (from staple fibres to a uniform fibre web) and hydroentanglement (to bond the fibres together and to get mechanically strong enough nonwoven).

It was possible to process the recycled fibres on a pilot scale. However, it has to be taken into account that the line speed, width and capacity were significantly lower when processing recycled fibres than in a commercial nonwoven line. Blending of recycled fibres with standard polyester fibres helped in the carding process. Broken fibres and dust formed during the carding step, and some fibres were stuck on the card and fell on the floor. Unopened material is a risk for the carding machines (Figure 37c). It was identified that the mechanical properties of the recycled fibres, dusting and uniformity of the recycled fibres are the clear improvement areas in the future. Due to the limited amount of the materials Suominen did not test the properties of the prototypes.



Figure 37 a) Mechanically recycled and bleached cotton fibres (left), and some fibres were lost in the carding process (right); b) Mechanically recycled cotton fibres from Laroche demo; c) Unopened material from the Laroche demo in the recycled fibre mix

### 5.2.5 Foam-Laid Nonwovens from Mechanically Recycled Fibres

Recycled fibres and especially those obtained from post-consumer markets have lost their length and strength, and mechanical shredding and opening will reduce them further. Therefore, they are not optimal for most textile processes, and currently their main application area is carded or air lay nonwovens. Also, wet nonwoven technologies that enable use of shortened recycled fibres are an attractive option. In this case, foam laying technology is represented as a novel route for mechanically recycled fibres.

The foam laying process is developed from wet-laying/paper making processes. Replacing water by an aqueous foam enables better formation and reduces the use of water, but is higher speed production process compared to other nonwoven processes.

The foam laying process can be used to produce thin paper-like structures and thicker nonwoven-like structures. The foam laying process is capable of utilizing very short fibre fractions such as side stream from mechanical recycling processes, mixtures of fibre materials and even residual dust from the shredding process.

Foam process was first tested in lab scale using two types of mechanically recycled materials: pre-consumer cotton fibres from Pure Waste Textiles (black) and post-consumer cotton from Laroche opening trials (Chapter 5.2.1). These were foam laid into sheet with cotton content in pulp ranging from 10 % up to 100 %. Formation of the samples were relatively good up to 80 % cotton content when observed from wire side. However, mixing of fibres in lab scale foam laying setup led to formation of fibre clumps observed especially in high cotton contents of 80 % and above. Appearance of selected foam laid sheets produced in lab scale are shown in Figure 38.



*Figure 38 Foam laid samples produced in lab: a) pre-consumer cotton (from Pure Waste Textiles) in mixtures with pulp: R-CO content 10 %, 20 %, 50 %, 80 %, 90 % and 100 %; b) difference between wire side and upper side of 80 % R-CO containing sample; c) & d) corresponding samples than in a) & b) but produced using post-consumer R-CO fibres from Laroche opening trials*

The foam laying process was also tested also in pilot scale using VTT Sampo pilot (Figure 39). Recycled, short cotton fibres were mixed with soft wood pulp fibres. The recycled textile fibres originated from mechanical opening process of worn-out jeans, thus being side stream of mechanical recycling process. Cotton fibre content varied from 10 % to 70 %. Product appearance (Figure 40) and



feel changed from a paper-like material to a softer, felt-like material with increasing the cotton content. Along with the addition of the cotton fibres, the strength and stiffness of the structure decreased due to the reduced fibre to fibre contacts in the pulp (Figure 41).

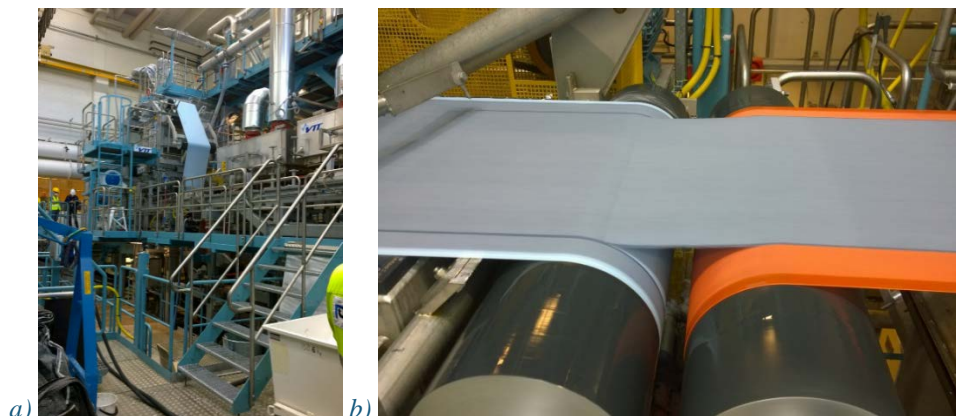


Figure 39 a) Foam laying line Sampo, and b) sample production on foam laying line



Figure 40 Samples produced from post-consumer CO-dust and pulp with foam laying technology. The CO fibre content ranged from 10 % (left) to 70 % (right)

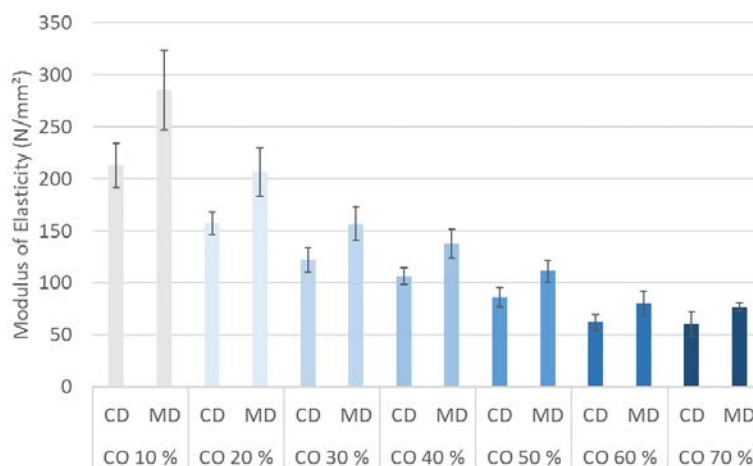


Figure 41 The effect of textile content on tensile properties in the foam laid samples with cotton, jeans dust content ranging from 10 % up to 70 %. (CD = cross direction, MD = machine direction)

Addition of binder fibres i.e. bi-component fibres composing of surface with lower melting point than the core, to the cotton fibre pulp mixtures enabled thermo-bonding of the foam-laid samples. Thermo-bonding was studied with two different bi-component fibre ratios (30 % and 40 %). The surface of the bi-component fibres started to melt at over 160°C. Low activation was visually observed already at 165°C, but the temperature rise further to 170°C and 175°C affected the strength and stiffness of sheet samples remarkably. Tensile tests to machine and cross direction (Figure 42) clearly show good isotropic property of the foam laid structure.

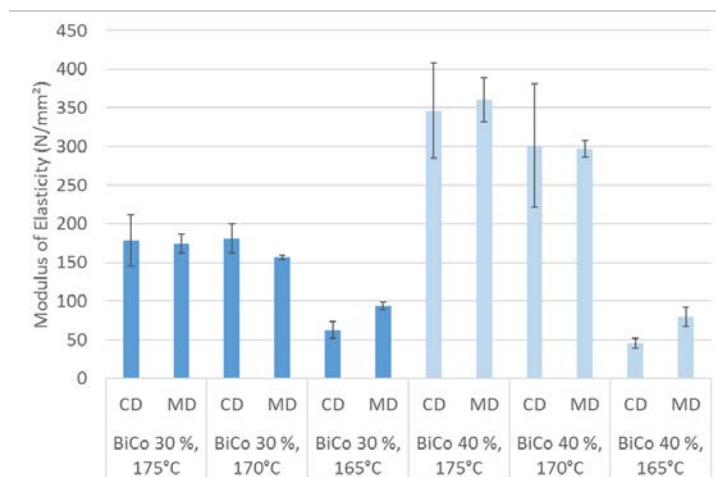


Figure 42 Effect of bi-component fibre content and activation temperature to tensile properties of foam laid samples

In conclusion, the foam laying technology enables manufacturing of variety of sheet-like materials. Higher production speed compared to other nonwoven processes can be achieved with the foam laying technology. Product appearance and feel can be adjusted from paper-like materials to felt-like materials by increasing the textile consumption. Thermo-bonding of low melt fibre fractions increases clearly the strength and stiffness of the structure. More detailed description of this demo is included as Annex 2.

## 5.2.6 Foam Formed Packaging Materials from Process Reject and Dust

Paptic is a producer of recyclable packaging material made of cellulose. The company aims at developing a new product including textile fibres, as textile recycling is an important topic within fashion industry.

In its demo, Paptic manufactured sheets including textile fibres on a laboratory scale but using the method that it normally uses in its production. Various textile fibre combinations were tested in the production of the sheets (Figure 43). The proportion of the short textile fibres utilized in the sheets was either 30% (+ 70 % cellulose) or 70 % (+ 30 % regenerated cellulose). The textile fibres used were post-consumer cotton, polyester (PET) as well as fibre dust. Pure Waste Textiles and Infinite Fiber Company supplied these materials.

The production of the sheets worked out rather well. The strength properties of the sheets including cellulose were, however, clearly better than of those without it. The sheets without cellulose were similar to felt fabric. By modifying the proportion of textile fibres it was thus possible to produce stronger and papery sheets or sheets that are felt-like. This means that it is possible to adjust the appearance and feel of the products by varying the textile consumption.

It may be possible to test the production of Paptic products including textile fibres on a larger scale in the future. The challenges of the tests will be, for example, optimization of the manufacturing process, the proportion of textile fibres and the properties of the products. However, utilization of textile fibres

in Paptic products on an industrial scale could have a lot potential. In addition, there may be demand for Paptic products including textile in the future.



*Figure 43 Textile fibre sheets made of post-consumer cotton, polyester (PET) and fibre dust*

### 5.3 Products form Mechanically Recycled Materials

#### 5.3.1 Towels Made from Post-Consumer Jeans

In the demo, worn out jeans were collected from customers in Finlayson's shops. The jeans were sent to Belgium for sorting and mechanical recycling. In addition, the recycled fibres were spun into yarn that was used to weave Old Jeans -towels (Figure 44a). The proportion of recycled cotton in the towels was 40 %. Other materials were viscose (40 %) and virgin cotton (20 %). These materials ensured the right content and quality of the yarn. The towels were not dyed, which saves water. It has been estimated, that compared to towels made of virgin cotton production of one Old Jeans -hand towel saves almost 850 litres of water and that of one Old Jeans -bath towel about 2 500 litres of water.

Finlayson collects also old undersheets and duvet covers in its shops. The fabrics are used to manufacture, for example, rag rugs and pillows (Figure 44b). The products are manufactured in Ostrobothnia, Finland.



*Figure 44 Old Jeans -towels and interior textiles made of old bed-sheets (Finlayson)*

#### 5.3.2 Acoustic Panels Air Laid Recycled Mat

Soften is a producer of acoustic panels and acoustics products. The company wants to develop business opportunities based on recycling and use of recycled materials. The purpose of this demo was to test all the felts made in Laroche pilots for their suitability for acoustic panels. The most suitable processing



parameters needed to be defined. The demos were done with a hydraulic press, Labtech Engineering LP-S-20 at Turku University of Applied Sciences.

In the demo, Soften produced a sample lot of acoustic panels using air-laid felts made of two types of recycled fibre mats obtained from Laroche (Chapter 5.2.1). Half of the materials was recycled cotton or recycled polyester, and second half composed of bi-component fibres (35 %) and new polyester fibres (15 %). The panels were manufactured using Soften's normal manufacturing process with production moulds. The thickness of the panels was 1500 g/m<sup>2</sup>. Appearance of selected panels are shown in Figure 45.

The acoustic properties of the test panels were compared to those of the standard panels of Soften at the laboratory of acoustics at Turku University of Applied Sciences. According to the results, air-laid nonwovens made of recycled fibres are rather well suitable for acoustic products. It is thus possible that a completely new product group based on recycled material can be developed. The key matter is, however, reliable and cost-effective supply of recycled fibres of uniform quality.



*Figure 45 Acoustic panel prototypes produced from Laroche demo nonwovens*

Mat containing more polyester was found to be the better for the application. However, dusting and poor die cutting can limit the usability of such materials in acoustic panels. It was also noticed, that the material variation in the felts produced at Laroche was high, which may decrease the acoustic properties. Due to the small size of the samples, it was not possible to test the acoustic properties of them.

### 5.3.3 Padding Material for Backpack from Air Laid felt

The felts from the Laroche processing pilot (Chapter 5.2.1) were also tested for their usability as a padding material in the backpacks of Globe Hope. These demos were also done with a hydraulic press, Labtech Engineering LP-S-20 at Turku University of Applied Sciences. The tested materials were compared to the foamed plastic mat that is currently used as a padding.

It was found out that the PP-based felt was the most suitable padding material from materials obtained from Laroche demo (Chapter 5.2.1). The PP-felt was much stronger than the plastic foam mat. There was no significant difference in the insulating properties between the PP-felt and the plastic foam mat. However, the water uptake of the PP-felt was remarkably higher than that of the plastic mat. On the other hand, it produced more dust than the mat. Furthermore, the felt was almost five times heavier than the foamed plastic mat.

#### 5.3.4 Air Laid Felt as Alternative for Cardboard

At Turku University of Applied Sciences, felt like materials from Laroche demo (Chapter 5.2.1) were tested in order to create alternatives for an Art Immersion® workshop frame<sup>27</sup> made from cardboard. In these demos, the following textile materials were used: thermo-bound and needle-bound felts from Laroche processing pilots (Chapter 5.2.1), recycled textile fibres, recycled textile flakes, virgin bi-component-PES, and adhesive textiles. The demos were carried out by forming textile mats with a hydraulic press, Labtech Engineering LP-S-20. Several material combinations were processed, appearance of selected samples are included in Figure 46. Three different frames were introduced to the owner of Art Immersion®, and the compressed felt made of the materials obtained from Laroche was chosen as the most suitable visually.

However, it was noticed that the high water uptake, dusting and poor die cutting might limit the use of the chosen material in this application. Impregnating textile waste with thermosets was also tested for this application. These demos were not tested further since the samples turned out to be too fragile and they broke easily.



*Figure 46 Materials produced with ArtImmersion demo: Compressed polyester sheet from materials obtained from Laroche trials on left and sheets covered with crushed textile pieces on right*

#### 5.4 Fibres from Chemically Recycled Cotton

Infinite Fibre Company process is able of utilizing recycled cotton textile, recycled pulp and standard or special dissolving pulps. The cellulose carbamate (CCA) process is a newfound process developed by VTT in Finland in an effort to create viscose grade staple fibres from textile waste. The process takes the waste, extracts and dissolves the cotton fibres, composing of cellulose, and creates new fibres via the carbamation route (Heikkilä *et al.*, 2018).

The process starts with sorting and tearing of the textile waste with shredder. The mass is conveyed to the bleaching and in order to remove silicates from the pulp and the mixture. The waste water is disposed of. The pulp is immersed with urea solution with proprietary compactor process and carbamated at elevated temperature and some ammonia created is removed with vacuum and scrubbed. The reacted pulp is milled before dissolving and the carbamate can be stored long times and transported easily as a dry powder.

The dissolving takes place in separate reactor with NaOH solution and there after the spinning process follows typical viscose process, but without harmful carbon disulphide. The solution is pumped via spinning bath that contains H<sub>2</sub>SO<sub>4</sub>, and Na<sub>2</sub>SO<sub>4</sub> is formed. The cellulose fibres are spun from the bath

<sup>27</sup> <https://www.taidesukellus.fi/frontpage>

and then stretched. Next the fibres are washed in and cut to size. Lastly, the fibres are after treated, dried and packed. Photographs from wet-spinning pilot located in VTT's Bioruukki piloting centre and appearance of fibres are shown in Figure 47. The fibres can be used for all same applications as viscose fibres are applied, nonwovens, wovens and knits as well different mixtures of fibre, for example, with cotton or PES. Within Telaketju Tekes projects they were tested in nonwoven demonstration by Suominen (Chapter 5.2.4).



*Figure 47 Generating viscose grade staple fibres from textile waste (Infinited Fibre Company)*

## 5.5 Thermal Recycling

Thermal recycling referring to melt processing can be used for fibre to fibre recycling. However, within Telaketju Tekes project all thermal recycling demonstrations involved melt processing as a route for production of composites.

### 5.5.1 Composite from Work Wear

Touchpoint recycled worn out work wear of its customers (Hesburger, Meyer Turku, Viking Line and Uudenmaan Sairaalaapetus) in co-operation with Dutch Awearness. The recycled clothes and surplus plastic (plastic reels) were utilized to produce composite material.

Worn out clothes can be utilized as raw material for composites that are used, for example, for outdoor furniture. The service model for the recycling of work wear is under development. In addition, the design of the outdoor furniture needs to be developed further.





Figure 48 Outdoor furniture made of composites (Touchpoint)

### 5.5.2 Testing of Blend Materials for Composite Production

Several material tests were run at Turku University of Applied Sciences in order to find suitable material combinations composite production. In these tests, opened textile waste fibres, namely polyester (PES) and cotton (CO), were mixed in different mixture ratios. In addition, to PES also virgin polypropylene (PP) fibres and virgin bi-component-PES were tested as melting ties. The trials were done with a hydraulic press, Labtech Engineering LP-S-20. The card webs were done manually with hand cards.

It was found out that PES required too high temperatures for melting and could not be used as a tie, because the CO-fibres started to burn. In order to be able to make adequate binding between the fibres, either PP-fibres or bi-component-PES would be required. The most suitable material combination was found to be 70 % (70 % PES and 30 % CO) + 30 % bi-component-PES. However, small variation in the PES/CO-ratio (70/30–80/20) or that in the proportion of the bonding bi-component-PES -fibre (20–30 %) did not have a significant effect on the felt quality. This was most probably due to inadequate manual mixing of fibres.

### 5.5.3 Injection Moulded Textile Composite

At Turku University of Applied Sciences, a composite material consisting of recycled PP and textile waste cut was processed and tested. Fortum's recycled PP-plastic was mixed with textile flakes (90 % PP and 10 % textile) and mixture was extruded into granulates. The granulates were injection moulded into test bars (Figure 49).



Figure 49 a) Prepared granulate-mix for extrusion, and b) Injection moulded test samples for mechanical testing: recycled PP on left and 90 % recycled PP + 10 % textile fibres on right

The test bars were mechanically tested with a Chimadzu tensile testing machine according to ISO 527. The testing speed was 50 mm/min. Appearance of test pieces after the tests are shown in Figure 50. The tensile behaviour showed that the textile acted as a filler in the polymer matrix. The mechanical strength of the textile composites was 75-85 % less than that of recycled PP. Also, the elongation of the composites was only 15 % of that of recycled PP. Based on the results, it can be assumed that there is no bonding between the textile fibres and the polymer. Further trials for finding a suitable bonding agent and for repeating these tests are recommended.

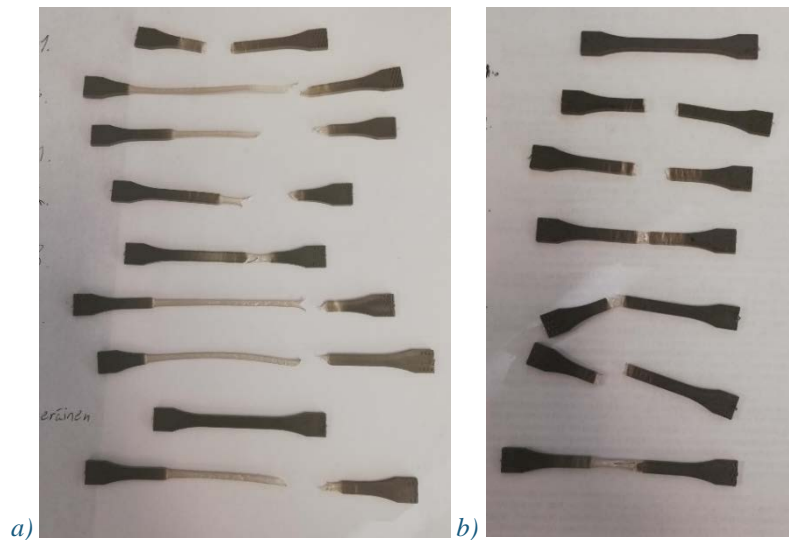


Figure 50 Tests bars after the tensile tests: a) recycled PP, and b) recycled PP composite containing 10 % textile fibres

#### 5.5.4 Recycling Pillows and Duvets

The aim of this demonstration was to find out whether it is possible to process thermoplastic composite using recycled bed linen without sorting and separating outer layers from filling of pillows and duvets. The sorting and separating process was omitted to be able to save on the handling costs. The demonstration material used was collected from consumers during Familon's recycling campaign that was carried out in March 2018.

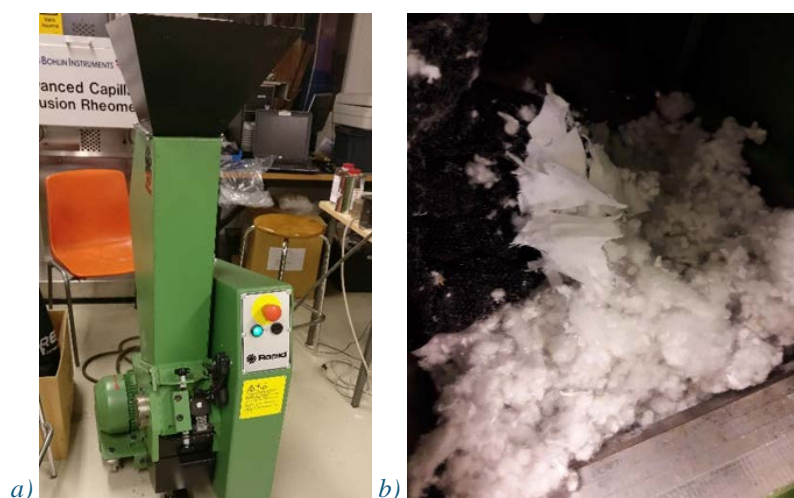


Figure 51 a) A crusher used in the trial was not effective enough to produce homogenous material. B) Large fabric pieces from the outer layers of pillows and duvets exist among polyester fibres after crushing



The pillows and duvets were processed into small and fairly homogeneous particles using a crusher at the Materials laboratory of Lahti University of Applied Sciences (Figure 51). This process was needed for further processing of the thermoplastic material. Unfortunately, it was found out that the used crusher was not suitable, because bits of the pillows and duvets tended to stick to the surface of the crusher. This is actually a typical problem when handling materials that are powdery and/or get static. Possible further studies would include use of blow aids in the crusher or opening fibres using tearing and combs.

### 5.5.5 Composites from Fluffy and Heterogeneous Textile Waste

VTT Modular Mixer (described in WO18037164 A1 Single screw extruder with hollow rotor member) is developed to process materials that are difficult or impossible to handle without additional processing steps with traditional plastic processing equipment. Such materials include heterogeneous bulky waste, fluffy material fractions, textile pieces and other heterogeneous material combinations. VTT's Modular Mixer benefits compared to traditional compounding technology include (Figure 52a & b), for example, large feeding zone without increasing the length or throughput, improved mixing with short screw length and accurate temperature control through large surface area and also through the inside of the hollow screw. During the process, post-consumer materials are exposed to heat treatment, which eliminates the need of additional cleaning stage of stained and (micro)biologically contaminated textiles (disinfection). Appearance of equipment is shown in Figure 52c.

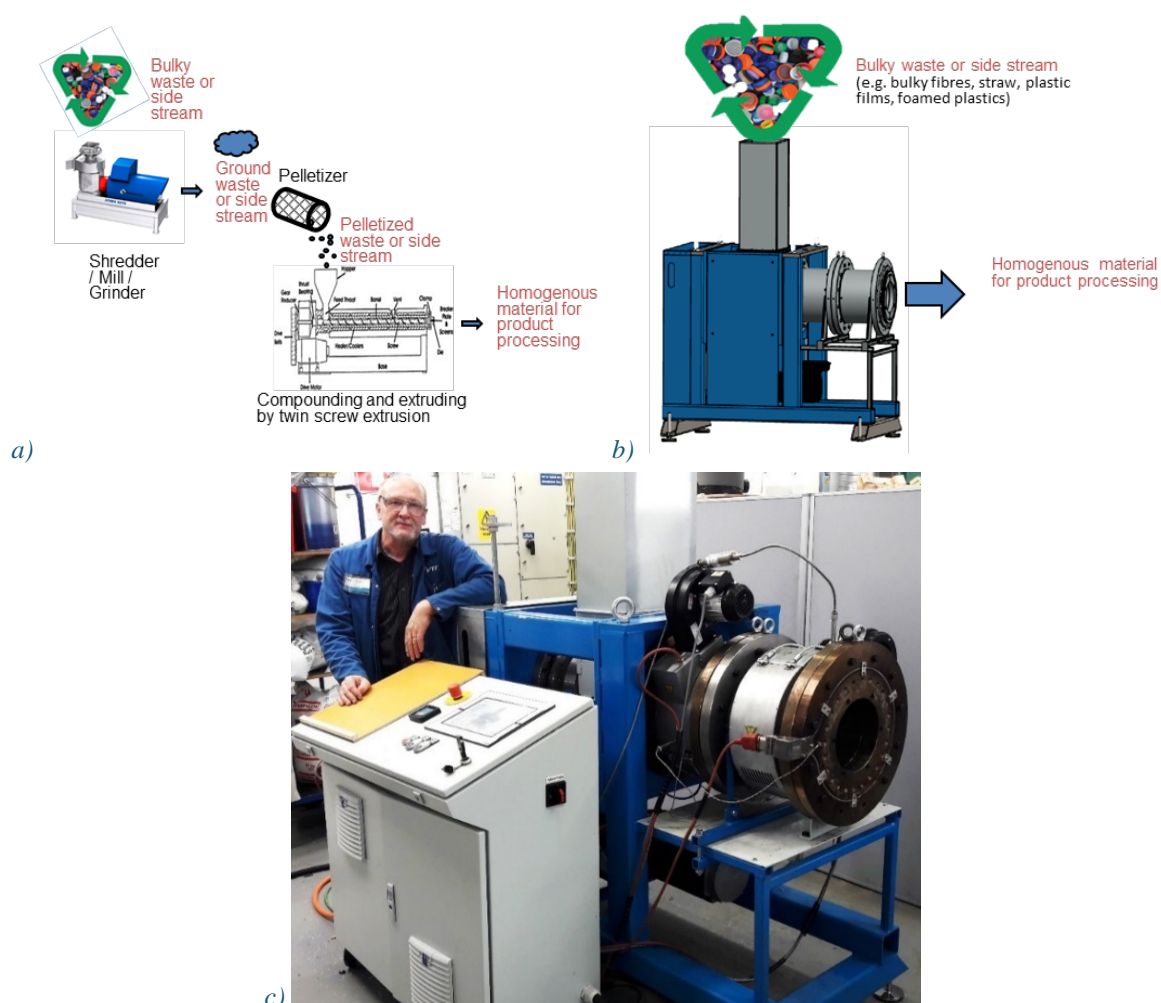


Figure 52 Comparison of a) traditional plastic processing steps to, b) alternative processing solution with c) Modular Mixer machine

Aim of the test trials was to represent novel thermal processing technology with Modular Mixer. This machine enables processing of fluffy material fractions. Target was to reduce pre-treatment cycles before final processing. Composites were processed from different fibre formulations by melting the PP-fraction of the mixtures (from 34 to 60 % CO or PET-fibres). Post-consumer and industrial waste polyester fabrics were melted alone to the compacted form. Finally pillows without removing the surface fabric were fed to the Modular Mixer and melted to composites (Figure 53).



*Figure 53 a) Feeding of quarter pillow with surface fabric to the Modular Mixer and b) resulting compound from pillow (Note: Surface fabric indicated with red circle)*

Feeding and compacting of all material combinations was possible with Modular Mixer. When feeding was relatively constant, no difficulties was observed in the process. Big clumps caused rising torque and few times screw stopped rotation. Short backward rotation enabled further material feeding to the system. Selected formulas were injection moulded to rectangle bars (Figure 54).



*Figure 54 Processing steps from starting material to injection moulded bar a) 60 % polyester post-consumer + 40 % PP industrial waste b) 100 % polyester stripes c) pillow (filling 100 % polyester and outer surface 100 % cotton)*

Results were very promising and Modular Mixer has showed it's potential to exploit multiple types of textile fractions in composite materials (e.g. in extrusion and injection moulding). It could be best utilized with low value fractions that are not suitable for mechanical recycling. More detailed description of this demo is included as Annex 3.

## 6. Impact of Telaketju

### 6.1 Dissemination Activities

#### 6.1.1 Publications and Visibility in Media

The Telaketju consortium was actively communicating the project, textile recycling, circular economy and of course the project results. The Telaketju website (<https://www.telaketju.fi/>) and the Facebook pages (<https://www.facebook.com/poistotekstiili/>) were built for communication and to publish results of the project. The Facebook pages have over 1 700 followers (January 2019).

Textile recycling and circular economy related topics were frequently raised up in different media. Often journalists and reporters also contacted members of Telaketju groups for interviews. Selected examples of our communication activities are listed in Table 10. Results and work carried out in Telaketju Tekes project has also been published in more detail and results have been (and are planned to be) published in scientific forums. The conference and seminar presentations and papers as well as the separate technical and scientific publications and reports are listed in Table 11. The students that were involved in the Telaketju Tekes project through their work are presented in Table 12. The summary of the project communication activities and media hits is given in Table 13.

*Table 10 Selected examples of general communication activities of the Telaketju project given in English and/or presented in international forums*

Date	Event / Media / Author	Title / Topic / Description / Link
8.5.2017	ForestTech Newsletter, VTT, Sara Paunonen	Developing a business ecosystem around Finnish discarded textiles <a href="http://www.foresttech.fi/news/news/1288-developing-a-business-ecosystem-around-finnish-discarded-textiles#.WRAeXyKwfDC">http://www.foresttech.fi/news/news/1288-developing-a-business-ecosystem-around-finnish-discarded-textiles#.WRAeXyKwfDC</a>
5.-6.6.2017	World Circular Economy Forum, Helsinki, Finland	Telaketju booth in <a href="https://www.sitra.fi/en/projects/world-circular-economy-forum-2017/#wcef2017">https://www.sitra.fi/en/projects/world-circular-economy-forum-2017/#wcef2017</a>
7.-8.6.2017	6 <sup>th</sup> International Fibre Recycling Symposium, Manchester, UK, Harlin A. <i>et al.</i>	Oral presentation: Development of Textile Recycling Chain in Finland – Insights of TELAKETJU Project
7.-8.3.2018	Circular Materials Conference, Gothenburg, Sweden, Harlin A.	Oral presentation: Solving complex textile recycling - from ideas to piloting
18.9.2018	Towards Circular Economy of Textiles, Telaketju international seminar, Espoo, Finland	Organized by Telaketju Tekes project & Finnish Fashion & Textile, 116 participants presentations available <a href="https://telaketju.turkuamk.fi/tietopankki/seminaarimateriaalit">https://telaketju.turkuamk.fi/tietopankki/seminaarimateriaalit</a>
26.-27.9.2018	Textile International Forum & Exhibition 2018, Taipei, Taiwan, Heikkilä P.	Oral presentation: Building New Business Ecosystem Around Textile Recycling <a href="https://cris.vtt.fi/en/publications/building-new-business-ecosystem-around-textile-recycling">https://cris.vtt.fi/en/publications/building-new-business-ecosystem-around-textile-recycling</a>
12.12.2018	Used Textiles: Waste or Value?- conference, Tallinn, Estonia, Heikkilä P.	Oral presentation: Telaketju - A national approach to circular textile eco-system <a href="https://cris.vtt.fi/en/publications/telaketju-a-national-approach-to-circular-textile-eco-system">https://cris.vtt.fi/en/publications/telaketju-a-national-approach-to-circular-textile-eco-system</a>
26.3.2019	Specializing in bio- and circular economy in the Baltic Sea Region -seminar, Tampere, Finland, Heikkilä P.	Oral presentation: Practices and International Prospects in Textile Circulation <a href="http://www.baltic.org/wp-content/uploads/2016/04/VTT_Heikkila.pdf">http://www.baltic.org/wp-content/uploads/2016/04/VTT_Heikkila.pdf</a>

*Table 11 The technical and scientific publications and reports of the project*

Type	Authors	Title / Information / Web link
Conference presentation and paper	Hinkka V., Heikkilä P., Harlin A.	Logistics Preconditions for Economical Reuse of End-of-life Textile. Presented in the Hamburg International Conference of Logistic in Hamburg, Germany, 13-14.9.2018. <a href="https://cris.vtt.fi/en/publications/logistics-preconditions-for-economical-reuse-of-end-of-life-texti">https://cris.vtt.fi/en/publications/logistics-preconditions-for-economical-reuse-of-end-of-life-texti</a>
Conference poster	Saarimäki E. Heikkilä P., Lehmonen J., Siilasto R., Kamppuri T., Harlin A	Foam laying technology as a novel route for mechanically recycled fibres. International Conference on Recycling of Textiles and Plastics in Bruges, Belgium, 13.-14.11.2018
Conference poster	Kamppuri T., Pitkänen M., Heikkilä P., Harlin A., Saarimäki E., Mattila I., Niemeläinen M.	Airborne dust from mechanically recycled cotton during ring spinning. International Conference on Recycling of Textiles and Plastics in Bruges, Belgium, 13.-14.11.2018
VTT Technology Report 343	Heikkilä J., Heikkilä P.	Tekstiilit varmasti kiertoon: Haasteet ja riskien hallinta tekstiilien kierrätyksessä. VTT Technology, no. 343 <a href="https://www.vtt.fi/inf/pdf/technology/2018/T343.pdf">https://www.vtt.fi/inf/pdf/technology/2018/T343.pdf</a>
A report published by TUAS	Heinonen E., Nurmi P.	Vastuullisuus julkisissa tekstiilihankinnoissa - Miksi yrityksen kannattaa tarjota vastuullisia tuotteita ja palveluja julkisille markkinoille? <a href="https://storage.googleapis.com/turku-amk/2018/05/vastuullisuus-julkisissa-tekstiilihankinnoissa_id.pdf">https://storage.googleapis.com/turku-amk/2018/05/vastuullisuus-julkisissa-tekstiilihankinnoissa_id.pdf</a>
VTT Research Report	Kamppuri T., Heikkilä P., Pitkänen M., Hinkka V., Viitala J., Cura K., Zitting J., Lahtinen T., Knuutila H., Lehtinen L.	Tunnistusteknologiat tekstiilien kierrätyksessä. VTT Tutkimusraportti VTT-R-00092-19 <a href="https://cris.vtt.fi/en/publications/tunnistusteknologiat-tekstiilien-kierr%C3%A4tyksess%C3%A4">https://cris.vtt.fi/en/publications/tunnistusteknologiat-tekstiilien-kierr%C3%A4tyksess%C3%A4</a>
VTT Research Report	Kamppuri T., Pitkänen M., Heikkilä P., Auranen A., Saarimäki E., Cura K., Zitting J., Knuutila H., Mäkiö I.	Tekstiilimateriaalien soveltuvuus kierrätykseen. VTT Tutkimusraportti VTT-R-00091-19 <a href="https://cris.vtt.fi/en/publications/tekstiilimateriaalien-soveltuvuus-kierr%C3%A4tykseen">https://cris.vtt.fi/en/publications/tekstiilimateriaalien-soveltuvuus-kierr%C3%A4tykseen</a>
VTT Research Report	Hinkka V., Heikkilä P., Harlin A.	Tekstiilikierrätyksen prosessien kustannusmallinnus, VTT Tutkimusraportti VTT-R-06611-18 <a href="https://cris.vtt.fi/en/publications/tekstiilikierr%C3%A4tyksen-prosessien-kustannusmallinnus">https://cris.vtt.fi/en/publications/tekstiilikierr%C3%A4tyksen-prosessien-kustannusmallinnus</a>
Seminar* presentation	Kokko M.	Practical aspects of end-of-life textile collection. <a href="https://storage.googleapis.com/turku-amk/2018/09/3-1_kokko.pdf">https://storage.googleapis.com/turku-amk/2018/09/3-1_kokko.pdf</a>
Seminar* presentation	Hinkka V.	How to produce recycled textile raw material at reasonable price? The effect of different textile collection and processing practices on price, <a href="https://storage.googleapis.com/turku-amk/2018/09/3-2_hinkka.pdf">https://storage.googleapis.com/turku-amk/2018/09/3-2_hinkka.pdf</a>
Seminar* presentation	Kamppuri T.	Suitability and identification of textile waste as a raw material for different processes, <a href="https://storage.googleapis.com/turku-amk/2018/09/3-3_kamppuri.pdf">https://storage.googleapis.com/turku-amk/2018/09/3-3_kamppuri.pdf</a>
Seminar* presentation	Saarimäki E.	Demonstrating new materials and products from recycled textile fibres, <a href="https://storage.googleapis.com/turku-amk/2018/09/3-4_saarimaki.pdf">https://storage.googleapis.com/turku-amk/2018/09/3-4_saarimaki.pdf</a>
* Towards Circular Economy of Textiles -seminar (more information in Table 10)		



*Table 12 The theses and other student works carried out by students related to Telaketju Tekes project and its preparation*

Type	Author(s)	Title / Information / Web link
Bachelor's Thesis	Mäkiö I.	Poistotekstiiliketjun roolikartta ja johdonmukainen viestintä. The role map of and coherent communication design for a post-consumer textile chain. Turku University of Applied Science, 2016, 40 p. Supervised by Ulla Seppälä-Kavén
A thesis	Auranen A.	Tekstiilijätteestä mekaanisesti kierrätetty kuitu ja sen soveltuvuus eri prosesseihin. Reclaimed Fiber and Its Suitability for Different Processes. Metropolia University of Applied Science & VTT, 2018, 47 p. Work related to Telaketju was supervised by Taina Kamppuri and Pirjo Heikkilä, VTT
A student literature work	Heinonen E.	Work related to public procurement. Turku University of Applied Science Published as a separate report, see Table 11.
A design work	Cowley S., Hagelin H., Kotiranta M., Pietarinen E., Kurttila R., Salonen E., Valtonen E., Kochetkova M., Holopainen E., Juntunen J., Oksanen L., Virtanen K., Hirvonen E., Ailoranta N., Konka V.	The course Creative design methods included as demonstration (Chapter 5.1.1). Lahti University of Applied Sciences, Supervised by Minna Cheung
A poster in the Telaketju seminar 10.4.2018	Haapala E., Johansson M., Kankare E., Nurminen M., Saukkoriipi O., Silokoski A.	Tekstiilien EKO-merkintä -kartta. Ecolabels of textiles. Turku University of Applied Science <a href="https://storage.googleapis.com/turku-amk/2018/04/haapala-et-al_tekstiilien-eko-merkinta-kartta_poster.pdf">https://storage.googleapis.com/turku-amk/2018/04/haapala-et-al_tekstiilien-eko-merkinta-kartta_poster.pdf</a>
Bachelor's Thesis	Kokko M.	Poistotekstiilin keräystapojen vertailu/Practical aspects of end-of-life textile collection, Turku University of Applied Science Supervised by Henna Knuutila
Bachelor's Thesis	Zitting J.	Optical sorting technology for textile waste: Development of an identification method with NIR spectroscopy, (2017). Lahti University of Applied Sciences. Available: <a href="http://urn.fi/URN:NBN:fi:amk-2017112918739">http://urn.fi/URN:NBN:fi:amk-2017112918739</a>
A student practice work	Rintala N.	Textile identification and sorting trial using the REISKAtex® sorting unit Responsible for trials planning and arrangement, Lahti University of Applied Sciences
Bachelor's Thesis	Engblom I.	Home, hyönteiset ja hiirenkakka - kuluttajapoistotekstiilien puhdistus lajittelussa. Mold, maggots and mouse droppings- purification of post-consumer textiles in the sorting phase Turku University of Applied Science, 2019, 55 p Supervised by Henna Knuutila



Table 13 The targeted and realized amounts of different types of publications

Publication categories	Targeted amount	Realized
Own communication of partners and funding organizations (media releases, newsletters etc., events)	not specified	21
Presentations about and/or including Telaketju in national seminars, workshops etc. events	3	25
Other national events where Telaketju somehow present	5	19
National publications including articles, blogs, webinars altogether	15	32
including webinars and videos	2	17
International events (conferences, seminars, workshops) altogether	7	17
including scientific publications	2	3
Media hits (in Finnish media)	3	54
Facebook followers (8.5.2019)	not specified	1912
Telaketju webpage visits (14.4.2019)	not specified	15021

### 6.1.2 New Projects

New project activities have been planned and launched in order to disseminate the obtained results and knowhow, and to increase the impact of the Telaketju action altogether. Examples of these are listed below.

- Telaketju TEM project. Support for *Lounais-Suomen Jätehuolto* targeting circular economy investment and development of end-of-life textile processing plant. Funded by The Ministry of Employment and the Economy. Duration 8/2018-7/2020
- Telaketju AIKO project. Support for *Lounais-Suomen Jätehuolto* for the implementation of the first phase of the end-of-life textile processing plant in Southwest Finland and the planning of later phases. Funded by Regional Council of Southwest Finland. Duration 5/2018-4/2019
- Circular Nordic Bio Nonwoven in MedTech Applications (NordicBio) project. Swedish-Finnish co-operation project coordinated by Wargön Innovation. Project aims for developments and pilot scale demonstration of a cost effective, bio and circular material based nonwovens suitable for medical applications, thus cleaning process for mechanically recycled fibres is included in the scope of project. Finnish side including VTT and *Pure Waste Textiles* funded by Business Finland and Swedish side by Vinnova. Duration 9/2018-5/2020
- Circular Economy Catalysts: From Innovation to Business Ecosystems (CICAT2025)<sup>28</sup> accelerates Finland's strategic aim to become the global leader in circular economy (CE) by 2025. Project aims to assist CE actors to transform their innovations into profitable business by catalysts of CE. Project is coordinated by Tampere University. *Turku University of Applied Sciences* is partner of this project and Telaketju action is one of the ecosystems that will be studied during CICAT2025. Funded by The Strategic Research Council (SRC) at the Academy of Finland. Duration 2018-2023.
- Business from Circular Economy of textiles (Telaketju 2) BF project proposal. Co-Innovation type project composing of public research part and company projects and funding. R&D partners include VTT, *Turku University of Applied Sciences* and *Lahti University of Applied Sciences*, and company project proposals included 3 companies and 19 funders including 4 organization from Telaketju Tekes consortium, and 3 from Telaketju YM consortium. Targeted duration 5/2019-4/2021. Funding applied from Business Finland in 2/2019.

<sup>28</sup> <https://cicat2025.turkuamk.fi/in-english/>

## 6.2 Networking of the Telaketju project

The Telaketju Tekes project networked nationally and internationally. Examples of the networking are presented in Table 14.

Table 14 Networking of the Telaketju project with national and international organizations and projects

Organization / Project	Description, additional information
BSR Stars S3 project <sup>29</sup> , multinational	<ul style="list-style-type: none"> <li>Textile recycling group work in match-making event held by BSR Stars S3 project in Tampere 7.4.2017</li> <li>Presentation given by Pirjo Heikkilä (VTT) in final seminar of BSR Stars S3 project in Tampere, 26.3.2019</li> </ul>
C&A foundation	<ul style="list-style-type: none"> <li>Susan Stuebing (Origame) interviewed Pirjo Heikkilä, Inka Mäkiö and Sini Ilmonen (Telaketju) on behalf of C&amp;A foundation 26.3.2018 in Espoo</li> <li>Telaketju is mentioned in report <i>Governance for the Circular Economy: Leadership observations</i>, available at <a href="https://cirql.eu/">https://cirql.eu/</a></li> </ul>
Circle economy, Netherlands Fibersort project <sup>30</sup>	<ul style="list-style-type: none"> <li>Henna Knuutila from TUAS and Pirjo Heikkilä from VTT are members of the expert group of the Fibersort project. They have participated in the follow-up meetings and have exchanged information.</li> <li>Jaakko Zitting (Lahti UAS) visited Fibersort Demo Day in Amsterdam, 14.3.2018</li> <li>Many Telaketju partners participated in the excursion 8.-9.10.2018 organized by Finnish Textile &amp; Fashion to Netherlands including presentation by Circle economy and visit to facility having operation Fibersort line</li> </ul>
Ellen MacArthur Foundation, England	<ul style="list-style-type: none"> <li>A mutual introduction during an online meeting 3.4.2017 between representatives of Ellen MacArthur Foundation and Pirjo Heikkilä and Jukka Heikkilä from Telaketju.</li> <li>A follow-up call 26.4.2018 and an invitation to Telaketju companies to participate in foundations <i>Circular Fibres Initiative</i></li> <li>Telaketju experts Kirsti Cura, Jukka Heikkilä, Pirjo Heikkilä and Sini Ilmonen were contributors to the report <i>A new Textiles economy: Redesigning Fashion's Future</i> <a href="https://www.ellenmacarthurfoundation.org/assets/downloads/publications/A-New-Textiles-Economy_Full-Report.pdf">https://www.ellenmacarthurfoundation.org/assets/downloads/publications/A-New-Textiles-Economy_Full-Report.pdf</a></li> </ul>
IVL, Sweden <sup>31</sup> SIPTex project <sup>32</sup>	<ul style="list-style-type: none"> <li>A mutual introduction during an online meeting between IVL and Telaketju and planning common activities 27.11.2017</li> <li>A joint study of textile identification carried out by Lahti UAS, IVL, and VTT (Chapter 4.2.2)</li> <li>Maria Elander from IVL gave a presentation about SIPTex project in the international Telaketju seminar 18.9.2018. Available: <a href="https://storage.googleapis.com/turku-amk/2018/09/1-5_elander.pdf">https://storage.googleapis.com/turku-amk/2018/09/1-5_elander.pdf</a></li> </ul>

<sup>29</sup> <http://www.bsr-stars.eu/bsr-stars-s3/>

<sup>30</sup> <https://www.circle-economy.com/case/fibersort/#.XFmRnMd7nmQ>

<sup>31</sup> <https://www.ivl.se/english/startpage.html>

<sup>32</sup> <http://boergroup-recyclingsolutions.com/projects/siptex-swedish-innovation-platform-for-textile-sorting/>

Organization / Project	Description, additional information
Kiertovillasta kasvuun, Circular wool, Metropolia Uni. Applied Sciences, Finland	<ul style="list-style-type: none"> <li>Inka Mäkiö gave general presentation of Telaketju action in final seminar of Circular wool project 16.5.2017</li> <li>Phone meeting 26.10.2017 between Telaketju and Metropolia University of Applied Sciences for planning possible co-operation</li> <li>Marja Amgwerd from Metropolia gave a presentation about wool project results in the national Telaketju networking seminar 8.4.2018 Available (in Finnish): <a href="https://storage.googleapis.com/turku-amk/2018/04/5_amgwerd-marja_kiertovilla.pdf">https://storage.googleapis.com/turku-amk/2018/04/5_amgwerd-marja_kiertovilla.pdf</a></li> </ul>
Laroche S.A. <sup>33</sup> , France	<ul style="list-style-type: none"> <li>17 people from 10 organisations and stakeholders of the Telaketju project visited Laroche (the manufacturer of textile recycling lines) 24.-25.1.2018.</li> <li>The visit took place during the pilot runs carried out for demonstration purposes (Chapter 5.1). The travel report (in Finnish) available: <a href="https://telaketju.turkuamk.fi/blogi/opintomatka-ranskaan/">https://telaketju.turkuamk.fi/blogi/opintomatka-ranskaan/</a></li> </ul>
Micellaneous Finnish stakeholders, Finland	<ul style="list-style-type: none"> <li><i>Tekstiileistä uutta liiketoimintaa</i> (New business out of textiles) workshop organized by Telaketju, the Council of Tampere Region and the City of Tampere in Tampere, 20.9.2017</li> <li>A national Telaketju stakeholder meeting, in Espoo, 10.11.2017, 12 presentations from YM and Tekes projects. 45 participants from 26 organizations</li> <li>Telaketju plans and project presented to sustainability group of Fashion and Sports Commerce Association (TMA)<sup>34</sup> in 2.12.2016 and 28.2.2018</li> <li>VTT, Touchpoint and IFC attended the event D.Day for Bioeconomy organised by Tekes in Espoo, on the 5.9.2017 in Espoo. The companies gave their presentations and Pirjo Heikkilä from VTT chaired a workshop dealing with digitalization in circular economy of textiles.</li> <li>The National Telaketju seminar in Innopoli, Espoo Finland, Networking event to build up a national recycling ecosystem of textiles, presentations (in Finnish) are available <a href="https://telaketju.turkuamk.fi/tietopankki/seminaarimateriaalit">https://telaketju.turkuamk.fi/tietopankki/seminaarimateriaalit</a></li> <li>Public webinar about Telaketju YM and Tekes project results and plans for the future, 12.4.2019</li> </ul>
Mistra Future Fashion (MFF) project <sup>35</sup> , Sweden	<ul style="list-style-type: none"> <li>Pirjo Heikkilä and Catharina Hohenthal from VTT, Jukka Pesola and Noora Alhainen from Pure Waste and Outi Luukko from Touchpoint attended the annual seminar organised by the MFF program in Stockholm, 27.-28.9.2017.</li> <li>Sigrid Barnekow, the coordinator of MMF gave a presentation in the international Telaketju seminar 18.9.2018. Available: <a href="https://storage.googleapis.com/turku-amk/2018/09/1-3_barnekow.pdf">https://storage.googleapis.com/turku-amk/2018/09/1-3_barnekow.pdf</a></li> </ul>
Nordic-Baltic networking project <sup>36</sup>	<ul style="list-style-type: none"> <li>Phone meeting 12.9.2018 between Telaketju project and involved in Nordic-Baltic project</li> <li>Pirjo Heikkilä presented Telaketju project in kick-off seminar of project - <i>Used Textiles: Waste or Value?</i> 12.12.2018 in Tallinn</li> </ul>

<sup>33</sup> <https://www.laroche.fr/en>

<sup>34</sup> <http://www.textile.fi/>

<sup>35</sup> <http://mistrafuturefashion.com/>

<sup>36</sup> <https://www.sei.org/projects-and-tools/projects/towards-a-nordic-baltic-circular-textile-system/>

Organization / Project	Description, additional information
SITRA <sup>37</sup> , Finland	<ul style="list-style-type: none"> <li>Telaketju project had a booth in World Circular Economy Forum (WCEF) 5.-6.6.2017 in Helsinki</li> <li>An introduction of Telaketju action and future needs of textile recycling (VTT, LSJH) in Sitra 5.4.2018</li> <li>Merja Rehn from Sitra gave a presentation in national Telaketju networking seminar 10.4.2018, Available (in Finnish): <a href="https://storage.googleapis.com/turku-amk/2018/04/2_rehn-merja_sitra_suomen-rooli-siirtyma-kiertotalouteen.pdf">https://storage.googleapis.com/turku-amk/2018/04/2_rehn-merja_sitra_suomen-rooli-siirtyma-kiertotalouteen.pdf</a></li> <li>Views of Telaketju action included into Finland's national road-map for circular economy 2.0 published 13.3.2019. Available: <a href="https://www.sitra.fi/en/projects/critical-move-finnish-road-map-circular-economy-2-0/">https://www.sitra.fi/en/projects/critical-move-finnish-road-map-circular-economy-2-0/</a> and <a href="https://www.sitra.fi/en/cases/new-materials-textile-waste/">https://www.sitra.fi/en/cases/new-materials-textile-waste/</a></li> </ul>
Toom Textiil Ltd. <sup>38</sup> , Estonia	<ul style="list-style-type: none"> <li>12 people from 6 organisations and stakeholders of the Telaketju project visited the textile manufacturer Toom Tekstiil.</li> </ul>
UFF Humana, Estonia	<ul style="list-style-type: none"> <li>A visit to the environment and development organisation UFF Humana (10 people from 8 organisations and stakeholders of the Telaketju project)</li> </ul>
WRAP <sup>39</sup> , UK ECAP project <sup>40</sup>	<ul style="list-style-type: none"> <li>A mutual introduction during an online meeting 9.11.2017 between WRAP and Pirjo Heikkilä. The common interests include, e.g. the economic aspects of textile recycling.</li> <li>Cecile Martin &amp; Sinead Murphy from WRAP and Telaketju researchers from VTT, Turku UAS and LUAS had a networking dinner 17.9.2018 in Helsinki</li> <li>Cecile Martin gave a presentation and an update of the ECAP project in the international Telaketju seminar, 21.9.2018 <a href="https://storage.googleapis.com/turku-amk/2018/09/1-4_martin.pdf">https://storage.googleapis.com/turku-amk/2018/09/1-4_martin.pdf</a></li> </ul>

### 6.3 Feedback from the Companies

The companies involved in the Telaketju Tekes project have evaluated their feeling on the project as well its impact.

#### Second hand textile raw materials and vision-based machine sorting

Petteri Asikainen, Remeo<sup>41</sup>

Textile recycling in Finland has become a more attractive area to investigate, since the need of it is recognized but it does not exist here yet. Remeo's interest, as a waste collecting and processing company, in Telaketju-project has been to study the second-hand textiles as a source of recycled raw material and how to process the selected materials for further utilization. Remeo's basic study has included a second-hand textiles composition research and test trials of sorting, according to different materials, by using the artificial intelligent controlled robotic sorting system.

The material composition research showed us that the daily wear used by consumers consists of hundreds of different combinations of several textile materials (see example of post-consumer materials in Figure 55). Therefore, it will be crucial to find the most efficient way of sorting out the wanted fractions for further processing. Recognition of the textile materials is often difficult due to missing

<sup>37</sup> <https://www.sitra.fi/en/>

<sup>38</sup> <http://www.toomtekstiil.ee/en/>

<sup>39</sup> <http://www.wrap.org.uk/>

<sup>40</sup> <http://www.ecap.eu.com/>

<sup>41</sup> <https://remeo.fi/remeo-in-english/>



product labels or even wrong information on existing labels. Also, it is hard to just by touching the garment to say which materials it is made of.



*Figure 55 A Mix of various textiles from collection (Remeo)*

On an industrial scale, the manual sorting will not be fast or accurate enough. In addition, this research gave us valuable data to estimate, how big raw material volumes of certain materials could be available for operating the processing plant.

In this project, the machine vision has proven to be an excellent technology towards efficient textile material recognition. During the test trials with the robotic sorting system, we could recognize and sort out the main targeted textile materials at 92-98 % purity level. With the most wanted material, over 90 % cotton, the achieved purity level was even higher. Also, other common textile materials like wool, polyester, polyamide and viscose blends were identified on a good level. According to the test results, the efficiency and accuracy of recognizing different materials can be on a productive level. The further development should have a focus on finding mechanics for faster out picking of wanted material fractions.

To be able to continue the development work new domestic industrial level applications, which can utilize high volumes of pre-processed recycled textile materials, will have to emerge in the future. High volumes will decrease the unit processing costs and enable high investments which are unavoidable when building fully automated textile handling plants. To build a commercial network among the different actors a “from end to beginning” -chain is needed. This will create the specifications to the materials and clarifies the levels for necessary pre-processing. In addition to all this, there is a demand to increase the commercial value of recycled materials to a level, where profitable business is possible.

### Acoustic panels from recycled fibres

Sami Helle / Soften Oy<sup>42</sup>

During the project, Soften produced a sample lot of acoustic panels. The acoustic properties of the test panels made from recycled fibres were measured, and found to be suitable for the acoustic products. The work contained a lot of comparisons between different manufacturing methods, too.

The Telaketju project has awoken a lot of interest with our company. However, so far we have not seen any impact for the turnover of our company, yet. We have gained much visibility by being involved in the Telaketju project. It has strengthened our customers’ understanding of our company as an environmentally sound firm. However, in order to get the new products in the market, detailed information about the prize, quality and availability of the raw material is needed. In addition, homogeneity of the raw material is also an important property.

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<sup>42</sup> <https://www.soften.fi/en>

## Increasing knowledge and environmental responsibility via Telaketju

Mari Rahkola / Suominen Corporation<sup>43</sup>

During the project, we achieved a proof of concept that we can increase usage of recycled material in our production. It was found that the quality of the recycled fibres effects the nonwoven properties. Thus, the amount of recycled fibres used has to be adjusted on grounds of the product features, processability and the equipment used. In addition, the project made us more aware of our environmental responsibilities and increased our knowledge of the behaviour of recycled fibre materials.

In future, the awareness of the possibilities and benefits of using recycled fibre materials needs to be increased. For example, the range of products that can include recycled fibres is much wider than consumers usually think. In addition, new business opportunities for using recycled materials need to be explored.

## Homogenous post-consumer textile waste is a key for good quality fibres

Noora Alhainen / Pure Waste Textiles Oy<sup>44</sup>

The Telaketju project has had a vast impact on our business. First and foremost, the project has increased knowledge and know-how within our organisation. Looking back to when the project first started we have gained a whole lot of useful information on several themes on circular economy, post-consumer textiles, textile sorting and textile waste streams and fractions.

Different post-consumer waste qualities play an important role in our process and we have learned that we cannot yet rule out manual sorting completely, but the process needs to be a combination of both manual and automated sorting. We have been able to mechanically open several post-consumer waste qualities and further spin those fibres to yarns. During the project, we found that we can get good quality fibres out of high quality, homogenous post-consumer textile waste. The importance of sorting cannot be highlighted enough, though. In order to get spinnable fibres the raw material needs to be homogenous. The interest towards and demand of recycled post-consumer textile fibres are substantial. However, there is an increasing concern on the market about the cleanliness and chemical load of the post-consumer textile fibres.

As a result of this project we were able to produce a 20 Ne yarn (20 % mechanically opened post-consumer cotton/40 % mechanically opened pre-consumer cotton/40 % r-PET). We found that we are able to use 20-30 % post-consumer textile fibres in our yarns. However, we suggest that the post-consumer textile waste collected in Finland should be processed here at least to fibres before exporting. We will be able to commercialize a yarn quality that includes at least 20 % of post-consumer textile fibres. Also, thanks to the Telaketju ecosystem we have several new contacts for partnering up in the future. New projects have already been planned to solve issues with collection and sorting of post-consumer textiles.

In the future, we will be able to reduce the amount of post-consumer textiles ending up on landfills and/or incineration. Creating business possibilities in circular economy will generate jobs and set an example for other businesses. The sorting problem needs to be solved. Also, the pre-treatment of the post-consumer textile waste needs to be studied further i.e. removing trimmings, prints and thick seams and cleaning the raw material.

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<sup>43</sup> <https://www.suominen.fi/en/>

<sup>44</sup> <https://purewastetextiles.com/>



*Figure 56 Pure Waste t-shirt from pre-consumer fibres (Pure Waste)*

### Composite from work wear and sustainable service model

Outi Luukko / Touchpoint Oy<sup>45</sup>

Networking played one of the key roles to us in the project. Learning from / with the partners has been a great step to understand possibilities/edges regarding circularity and, on the other hand, to execute steps towards circularity in textile business. Even though Finland is a relatively small business area, this project has gathered innovative and skilled companies / teams together who want to learn and make a change.

At TouchPoint, we have played a role as a change agent in the market of work wear. At a concrete level, we were able to activate our network and carry out our pilots as planned, including collaboration with the Dutch Awearness value chain based in the Netherlands. Waste textiles are disposed of by incineration. Within the project we piloted with several Finnish companies, making composite from work wear in the end of their life cycle. Composite can be used as a construction material or for patio/restaurant furniture, for example. Composite material manufactured from textiles and plastic is very durable, saving a lot of emissions.

In addition, our other pilot was a sustainable collection of garments designed for healthcare services. This was also achieved. designed, is practically ready. Its innovative materials and model range have been developed and tested throughout the project.

TouchPoint was the first Nordic company to provide the working clothes sector with a circular economy service model that not only provides new working clothes, but also puts old textiles to use or at least takes care of their disposal, possibly by using them to create new materials. We have been able to create a resource wise service platform, which we can communicate growing our competitive edge.

The circular economy is still in its early stages in the textile industry, which is why pioneers in the field are needed. We have brought a change by bringing new solution models for implementing the circular economy. We have successfully inspired our customers, partners and stakeholders to make responsible choices, having been able to grow the segment of recyclable and regenerated fabrics instead of virgin materials. Focus in affecting the attitudes, growing awareness (CSR) and reducing environmental impact in textile production.

For us, the prospects and opportunities in the circular economy are expanding every day. We (all) need to focus our effort to challenge ourselves how we can make better and more responsible choices in business. We need to get the message through to the wider audience by offering tangible and feasible solutions.

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<sup>45</sup> <https://www.touchpoint.fi/en/>

To fasten up this development we need to work together with the partners sharing the same aim and values; to create tools to communicate better about circular business models and to measure the impacts of our actions / choices. We need to take steps further from initiatives to concretia.

### Mapping the needs and requirements in textile recycling

Oskar Engblom / Ari Ilmakunnas Oy<sup>46</sup>

During the Telaketju project we got a clear larger picture of the needs and requirements concerning processing and recycling of textiles and related materials; especially the issues that need to be taken into consideration before moving to the next stage of establishing a textile recycling facility in Finland.

The project also enabled us to meet new companies and contacts, which are working in our core industrial sectors. These contacts have already been valuable to us both directly and indirectly. Looking at our participation in retrospect I am very pleased that we decided to join Telaketju, as it gave us great new insights into this new industrial sector, which is currently being built around textile recycling and upcycling of textile goods. Based on these learnings we decided to change our own business model to cope better with the future needs and demands.

The actual impact of this project on our society and environment is yet to be seen, but personally I believe that it will be substantial. The recycling of textile waste will serve as a means of providing solutions to many economic, environmental and social issues. In view of these forthcoming developments and business opportunities, it is but natural to reduce the consumption of resources through recycling and up-cycling of products which are still today considered as waste.

As recycling in the textile mills dates back several decades but has become during the last decade a global multibillion industry in producing of innovative high value-added products which origins of waste. We should act fast to make sure that Finland will become one of the forerunners in this new industrial sector, where the aim is saving in resources of raw materials, energy water etc. and reducing the impact on environment for sustainable developments and products. In future, textile recycling would be as important industrial activity as textile manufacturing is today.

### Automation design and software development for textile sorting in pilot scale

Esa Taipale / MJV- Sähkö Oy<sup>47</sup>

During the Telaketju project, we participated in the construction of a pilot equipment for textile sorting for Lahti University of Applied Sciences. We carried out the electrical wiring and automation design and developed the software and the user interfaces for the pilot sorting plant.

For us, the main benefit of participating in the Telaketju project was the chance to get a good picture of the present challenges and possibilities associated with textile recycling and other utilization. Even though we are already strongly involved in circular economy in terms of processing other waste materials, the development of the software for the pilot textile sorting plant brought out the possibilities and challenges within the textile recycling sector. This field of activity turned out to be more complicated and challenging than we had thought. On the other hand, the Telaketju project brought together various players of the field and showed that by pooling their expertise it is possible to tackle the challenges and problems associated with textile recycling. We are thus looking forward to the beginning of the planning of the industrial textile sorting plant in Finland, and we hope to be able to participate in it with our expertise and knowledge. Legislation associated with recycling is, however, partially outdated in Finland and Europe, and the present situation does not necessarily promote, for example, textile recycling. Europe-wide legislation must thus to be updated as soon as possible. In

<sup>46</sup> <https://ilmakunnas.fi/>

<sup>47</sup> <http://www.mjv-sahko.fi/en/home.html>



addition, automation and further development of textile sorting demand yet a lot of work before sorting is feasible on an industrial scale.

### Essential knowledge for planning a Finnish refinery plant for end of life textiles

Sini Ilmonen / Lounais-Suomen Jätehuolto Oy (LSJH)<sup>48</sup>

For us, participating in the Telaketju project was worthwhile in several ways. Firstly, the project brought together a group of Finnish top experts and several entrepreneurs operating within the textile sector and other sectors, too. Secondly, it was possible to review and harmonize the terms and propose them for general use and propose some reforms to the legislation concerning the textile recycling sector. Lastly, we were able to model the collection system of end of life textiles and its costs within the operating area of Lounais-Suomen Jätehuolto that consists of 17 municipalities. In future, this modelling and acquired knowledge of collection, storing and sorting of textiles will form the basis for the collection of end of life textiles at the national level. In addition, we could start planning a Finnish refinery plant for end of life textiles and apply funding for it. The risk analysis report and the quality criteria for different refinery methods that were produced during the Telaketju project give tools and support the planning of the plant.

In future, we will continue this planning work in order to be able to establish the first refinery plant in Finland with public-private partnership. All in all, LSJH and other waste management companies will thus have better opportunities to get ready for the separate collection obligation for textile waste by year 2025. In addition, LSJH will be a pioneer in the research and methodology of processing post-consumer end of life textiles in Finland in the future.

From social and environmental points of view, refining end of life textiles will create basis for new industry that is based on ecologically sound and sustainable business. This kind of industry will also mean new jobs, technology development, domestic products, concepts and ways of doing cooperation even between competitors.

There are, however, areas that still need further development and work within the textile recycling sector. A nation-wide plan for textile collection and co-operation between textile collectors and sorters is needed and various scenarios and profitability of the refinery plant must be established. The quality of textile sorting must increase and access to recycled materials must be easy (and domestic). Development of products made of recycled materials must be enhanced by, for example, creating demos with Finnish utilizers of recycled materials.

### Developing a new recycled textile-based flexible packaging material

Daniela Bqain / Paptic Oy<sup>49</sup>

Paptic joined the Telaketju-project to showcase a new packaging material where recycled textile fibre is incorporated to the fibre matrix via foam laying. Currently Paptic produces a flexible packaging material where the main raw material is wood fibre, and then there are some bio-based biodegradable man-made fibres also (Figure 57). Two different types of sheets were produced; sheets with textile fibres and wood fibres, as well as sheets with textile fibres and bio-based man-made fibres.

Laboratory scale sheets were produced to see how the textile fibres act in our lab scale production process. From this we learned that by incorporating textile fibres into the process we were able to receive a totally new interesting packaging material that could possibly be used to produce e.g. carrier bags or other flexible packaging for sustainable brands. We also learned that there would be a demand for this kind of packaging material in the market.

<sup>48</sup> <https://www.lsjh.fi/en/>

<sup>49</sup> <https://paptic.com/>

The textile industry is very polluting and resource consumptive, so there is a need to make the industry more sustainable and circular. The amount of textile waste is so huge that we need to find more ways to utilize it. The Telaketju project brings different organisations, brands and industry players together and helps to develop strong partnerships across the whole value chain, which can further expedite the process of collecting, sorting, refining and utilizing end-of-life textiles.

Still a lot needs to be done regarding the use of recycled textiles. In general, there is a need for more facilities that can utilize recycled textiles and textile fibres, and there should be more product development regarding the utilization of these fibres. On our side, the same applies. We would need to allocate more research & development on experimenting with different fibres. Besides this we should test textile fibre usage on our pilot scale paper machine, because until now we have only tested textile fibres on a laboratory scale.



*Figure 57 Carrier bags made of flexible packaging material (Paptic)*

### Not simply recycling but regenerating new and better fibres

Kirsi Terho / Infinited Fiber Company Oy<sup>50</sup>

The main target to Infinited Fiber Company (IFC) in the Telaketju project was to be a part of creating a textile recycling network in Finland. IFC provides one new way of recycling textile waste by chemically recycling the cellulose fibres into new and better cotton-like fibres. While Telaketju project was running IFC was able to start the pilot production and test multiple times running the textile-based fibre production with good results. This proved that the process is working and can be one part of textile recycling value chain.

The impact of Telaketju project on our business is in the development of the textile recycling in Finland. It's very important to us to have a raw material available. We are also very happy with the results from the textile sorting because it's crucial to us to be able to separate the cellulose base textiles from the others at the certain level.

Telaketju project will have a long-lasting effect on companies involved as it challenged us to think more about the environmental impact the textile industry has. Lots of new ideas and solutions were investigated and the co-operation between the participants will go on in the future.

It's important to carry on with the path the Telaketju project directed. Promoting the recycling and increasing the awareness should be one of the main targets in the future. Making the recycling easy for

<sup>50</sup> <https://infinitedfiber.com/>

the consumers is something that will have a massive impact on piling textile mountains. We sincerely hope that the whole value chain will be done with a fruitful co-operation to ensure the rebirth of new industry.



*Figure 58 Infinite Fibers were used to produce fabrics to Helsinki Fashion Week's New Normal Collection (IFC)*

### Step by Step Towards Circularity

Elli Ojala / Finlayson Oy<sup>51</sup>

Telaketju project deepened our knowledge of Circular Economy in general and in Finland. With the help of the Telaketju-project we have introduced new products made of recycled materials. The products have been developed together with Finlayson's own suppliers. The share of recycled materials of all our materials increased from 0.3 % (2016) to 2.7 % (2017). Telaketju also was a great way to network and connect with other Finnish companies working with Circular Economy and recycling.

Circular Economy has been rooted more deeply into Finlayson's company DNA. We will strive to be the forerunner in Circular Economy in the Finnish home textile business. We introduced several new recycled products to the market; we increased the selection of rag products, designed new clothespins from surplus materials of the plastic industry, collected old jeans to manufacture towels in Belgium, introduced flannel sheets made from cutting waste, designed rugs from recycled PET-bottles and launched our new collection of duvets and quilts that have 100 % recycled polyester filling, some examples shown in Figure 59. At the end of the year 2017, we also launched the Finlayson Circular Economy account (Kiertotaloustili), which was a more responsible way to buy and recycle home textiles, but the project remained at pilot stage.

The aim of Telaketju initiative was to build a total concept of textile utilization from waste collection to final product is something that has not been done in Finland before. The multi-sectoral cooperation was unique, and it is not so often possible that waste companies, textile brands and research institutes get to collaborate for something big.

In our case, the biggest challenge still is the fact that Finlayson's products are mainly produced abroad. Thus, if we build a textile recycling facility in Finland, the material still needs to be turned into yarn, fabric and final product somewhere else, as currently we do not have the know-how or machinery to do

<sup>51</sup> <https://www.finlayson.fi/>

these steps in Finland on a large scale. Therefore, the global aspect of textile recycling concepts needs to be taken into account.



*Figure 59 New recycled textile products: towels made of collected old jeans (Finlayson)*

### Increasing competitiveness via Telaketju networking

Maikki Lukka / Familon Oy<sup>52</sup>

Our goal to participate in the Telaketju project was to increase Familon's circular economy expertise and bring the circular economy perspective to all of Familon's operations. We hoped to find circular economy solutions and ways to act as a more responsible partner. In addition, our aim was to find concrete solutions to utilize pillow and quilt consumer waste.

Familon carried out two separate projects in co-operation with Lahti University of Applied Sciences and Turku University of Applied Sciences. In the demo conducted by Lahti University of Applied Sciences, we surveyed the mechanical recycling possibilities for used pillows and duvets. The purpose of the other project with Turku University of Applied Sciences was to examine the composition of the pillows and duvets that were collected during the recycling campaign organized by Familon. Also, the project included benchmarking the recycling methods of these products.

As a result, we managed to get a better idea about the current status of recycling pillows and duvets worldwide. We also got useful information on the composition of the products returned in our pillow and duvet recycling campaign. In addition, we gained a better understanding of the challenges of mechanical recycling of pillows and duvets, through the testing of consumer waste material.

However, the most important benefit of the participation in Telaketju was networking with other companies and understanding that the circular economy cannot be ignored in business. During Telaketju, we have started to take better into account the circular economy perspectives in our operations, however, there is still much left to be done. Nevertheless, Telaketju served as an impetus for advancing circular economy issues at Familon. During Telaketju, we were able to complete our first sustainability review and learned how to communicate more effectively about CSR issues. All in all, Telaketju has increased our competitiveness, which was also one of our goals when taking part in the project.

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<sup>52</sup> <https://www.familon.fi/en/familon/>



## 7. Summary and Conclusions

Telaketju Tekes project targeted for development of new business opportunities based on circular economy of textiles. It is continuation of earlier work carried out by projects partners (see project descriptions from Chapter 2) and it focused on building knowledge base and developing processes for new value chains and on finding uses for different kinds of textile waste fractions. It composed of public research project and confidential company projects. Telaketju Tekes project was part of larger Telaketju action including funding from different sources. Furthermore, Telaketju Tekes project has been actively networked with other research projects in Finland as well as in Europe (see co-operation descriptions from Table 14). Telaketju action projects and related other past and current projects as well as suggested future projects are illustrated in Figure 60.

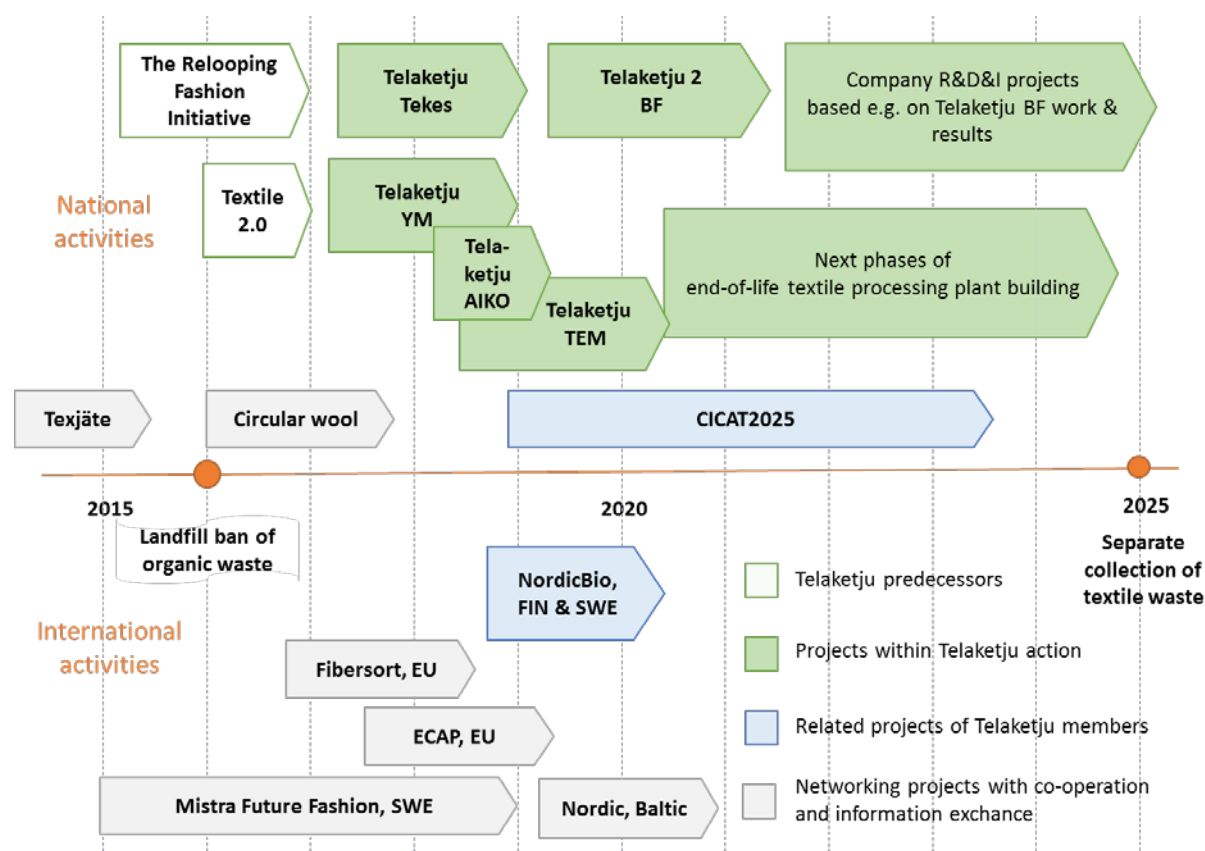


Figure 60 Telaketju and other related projects in a timeline. Project descriptions can be found from Chapter 2 and Table 14

During Telaketju Tekes project we have generated description of circular textile ecosystem in Finland with future development needs and vision. We have put lots of efforts out in order to build circular economy and sustainability know-how into Finnish companies. Many of the research activities have been aimed for facilitating textile recycling from collection and sorting to recycling processes. Furthermore, we have carried out a large number of trials and demonstrations carried out by research organizations and companies. These demonstrations were most part conducted in co-operation between partners, and many of them formed chains, which model possible future value chains. Main results and/or project outcome are summarized in Table 15, demonstrations listed in Table 16 and positioning of results and outcomes within ecosystem is illustrated in Figure 61.

*Table 15 Summary of the main results and outcomes obtained in Telaketju YM and Tekes projects*

	Results / Outcome	Project	Description
1	A summary of terms and legislation	YM, Tekes	Understanding of the terms related to textile recycling and legislation (with interpretations) affecting it. A report
2	Separate collection trial	YM	Within the Turku area, separate textile collection was tested at regional collection points and at housing cooperatives with and without guidance
3	Manual sorting pilots	YM, Tekes	The rate and accuracy of manual sorting in identification of particular fibre fractions was tested for industrial recycling
4	Sorter education	YM, Tekes	Production and assessment of material produced for the educational and work-based learning
5	Involving consumers	YM	A blog and other informing of circular economy and textile recycling that was aimed at consumers
6	Communication with experts	Tekes	A series of webinars dealing with textile circular economy issues, two public seminars (national networking seminar 10.4.2018 and international seminar 18.9.2018), 3 scientific publications, and 17 presentations/other contribution in international conferences, seminars, workshops and/or meetings
7	Responsibility	Tekes	Responsibility Workshop Series, spring 2018. The results of the workshops were reported in Finnish in the blog posts called Viestitään vastuullisesti (Responsible Communication).
8	Cost modelling	Tekes	Estimation of the costs of collection and pre-processing of textiles through cost modelling.
9	Demonstrations	Tekes, YM	Several demonstrations of various processes, materials and products were carried out
10	Risk management	Tekes	A report on risk management of textile recycling
11	Identification technologies for textile compositions	Tekes	Understanding of possibilities and limitations related to textile identification. A report (in Finnish) about the non-destructive identification technologies suitable for waste textile fibres and fibre mixtures containing also information about chemical safety issues regarding textile waste, its processing and products made of it.
12	Suitability of textile waste for recycling	Tekes	Information about the quality criteria of pre-processed waste textile materials and their suitability for different kinds of processes, applications and products. A report (in Finnish) about the quality criteria required by the different recycling processes, including identification and sorting possibilities harmful chemicals that possible might remain in the recycled textile material.
13	National and International Networking	Tekes, YM	Members of Telaketju projects have been networking nationally and internationally via visits, conferences, knowledge exchange, and direct co-operation.
14	Ecosystem building	Tekes, YM	Telaketju ecosystem has been built around a circular economy of textiles. It compose of companies and other organization who have the necessary knowledge and urge to higher sustainability.

Table 16 List of demonstrations carried out during the Telaketju Tekes project. Includes demonstrations carried out within companies

Type	Demonstration	
Product design	a	Creative design methods towards circular economy
	b	Ecological work wear for caring industry
Mechanical recycling	c	Opening and air-laying of recycled materials
	d	Ring spinning of mechanically recycled fibres
	e	Open end spinning of mechanically recycled fibres
	f	Carded nonwovens made of post-consumer cotton fibres
	g	Foam-laid nonwovens from mechanically recycled fibres
	h	Foam formed packaging materials from process reject and dust
Products form mechanically recycled fibres	i	Towels made from post-consumer jeans
	j	Acoustic panels air laid recycled mat
	k	Padding material for backpack from air laid felt
	l	Air laid felt as alternative for cardboard
Chemical recycling	m	Fibres from chemically recycled cotton
Thermal Recycling	n	Composite from work wear
	o	Testing of blend materials for composite production
	p	Injection moulded textile composite
	q	Recycling pillows and duvets
	r	Composites from fluffy and heterogeneous textile waste

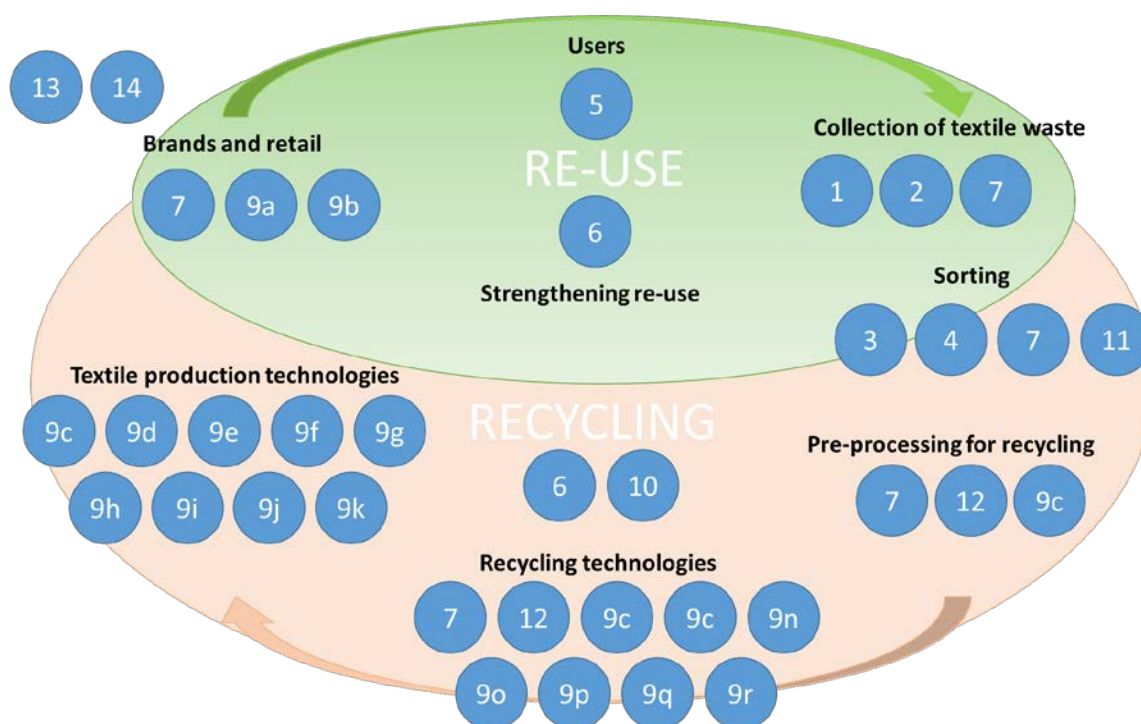


Figure 61 Illustration of positioning of Telaketju main results and outcomes within ecosystem building (numbers from Table 16)

In conclusion, Telaketju Tekes project successfully delivered one of its main expected outcome - to build a circular textiles ecosystem providing business opportunities, and composing of companies and other organization who have the necessary knowledge and urge to higher sustainability.

Almost all companies who participated Telaketju Tekes project raised up the value of networking and contacts with innovative and skilled companies and teams who all want to learn and make a change. Learning together, from and with the partners, and execute steps towards circularity, was seen as key issue towards the circular economy of textiles build up in Finland. During the project the companies have increased their knowledge and awareness both in technological issues, like behaviour of recycled post-consumer fibre materials, textile waste streams and fractions, textile collection, storing and sorting, and the products made of recycled textile materials, and in circular economy, new business models, and business possibilities related to textile recycling.

Companies have noticed some missing prerequisites for commercial action came up; absence of refinery plant for waste textile streams and detailed specifications for the textile waste material like quality criteria, homogeneity. Challenges related to sorting were also picked up, i.e. efficient automated textile material recognition and fast sorting system; however, manual sorting was seen as a necessary tool to separate textiles still suitable for their original use. In addition, detailed information on economic issues, which defines whether the profitable business will be possible, is still missing, e.g. processing and investment costs, prize and availability of textile waste material as well commercial value of recycled raw materials. Running business will also require new domestic level applications that will utilize high volumes of pre-processed recycled textile material, and facilities that are able to utilize recycled textiles and textile fibres.

Many of the companies involved in Telaketju Tekes considered that the project also has an influence on society and environment. It will provide a basis for new industry with ecological sound and sustainable business, new jobs, technology development, domestic products, concepts, ways for doing in co-operation between even competitor companies. It may also help to reduce amount of consumption of resources, prevent post-consumer textile waste ending up to landfill or incineration, and even being a good example for other business areas. Before this can come true, further development and knowledge is needed on efficient textile material recognition, fast sorting system and pre-treatment of the post-consumer textile waste, including cleaning the raw material. In addition, new business opportunities of products in which virgin materials could be replaced with recycled ones, and benefits of the use of recycled fibre materials in products, were seen worth to be explored. A nation-wide plan for textile collection, cooperation between collectors and sorters, and a commercial network among different actors, a “from end to beginning” -chain, were seen to promote the shift to circular economy of textiles, however, global aspects of textile recycling is necessary to clarify because main part of textile products’ production is nowadays abroad. Some of the companies pointed also out that Telaketju-consortium has awoken a lot of interest and gained visibility, even effected on company’s image as an environmentally sound, and even increased company’s competitiveness.

When we compare expectations and outcome of the project we can see that project has been successful (Table 17). We have been able to increase networking (WP1, O) and knowledge in companies about circular economy (WP2) and sustainability (WP5), and given them tools to take these into action (R4). We have gained experience and understanding of sorting and criteria (WP3), however these have not been formulated into form of set of specifications (R1 and R2). We have carried out large number of demonstrations (WP4, R3). Telaketju Tekes project has communicated actively and gained media interest (WP6). Even though same parts will need further work and development, we have been able to contribute and address all determined targets and expected outcomes.

Work towards higher circularity of textiles continues in companies and other organizations that participated as well as were linked with Telaketju network, and of course, within other Telaketju project activities too.



Table 17 Comparison of expectation and outcome of project ☺ = successful/realized, ☹ = partly done, but require more work, ☹ = unsuccessful/ not realized

		Target / goal	Outcome / realization	
Targets of WPs	WP1	Management of project; networking of companies; co-operation with other Telaketju activities and interests groups	Companies pleased with project management; networking and co-operation has been active.	☺
	WP2	Increase knowledge about circular economy related topics	Companies were able to communicate their needs and research partners made studies, reviews according to these needs. Information was available via workshops, webinars, seminars and project reports.	☺
	WP3	Practises and criteria and for sorting, and specifications to recycled materials	See general expected results 1-2.	☹
	WP4	Demonstrations with different textile waste fractions, using different technologies and study suitability of different materials for different applications	See general expected results 3.	☺
	WP5	Comprehensive understanding about sustainability and responsibility, and communication sustainability	Workshop series and webinars about sustainability, blog posts by companies who participated.	☺
	WP6	Publication and dissemination of results	Active communication and large media interest, new projects based on obtained results and knowledge.	☺
Expected main outcome (O)		Ecosystem with capabilities and willingness to advance textile recycling and circularity	Telaketju network has been getting wider, new research activities has been started.	☺
Expected general results (R)	R1	Quality criteria for manual and automated sorting	We have understanding about quality requirements related to processing and applications, but these were not formulated yet into form of set of specifications. More work is required for realization of this goal	☹
	R2	Specifications for sorted and pre-processed textile materials		☹
	R3	Demonstrations using widely different kinds of textile waste fractions	Demonstrations carried out from cotton, synthetic fibres and mixtures using mechanical, chemical and thermal recycling processes.	☺
	R4	Tools for companies to apply sustainability comprehensively in their activities	Information about circular economy related topics and sustainability has been made available for Telaketju partners.	☺

## References

- Act 445/2018 Laki jätelain muuttamisesta (Act on reformation the waste law) Available: <https://www.finlex.fi/fi/laki/alkup/2018/20180445#Pidp445164544>.
- Dahlbo H., Aalto K., Salmenperä H., Eskelinen H., Pennanen J., Sippola K., Huopalaisten M. (2015) Tekstiilien uudelleen käytön ja tekstiilijätteen kierrätyksen tehostaminen Suomessa, Suomen ympäristö 4 | 2015. Available: [https://helda.helsinki.fi/bitstream/handle/10138/155612/SY\\_4\\_2015.pdf?sequence=4](https://helda.helsinki.fi/bitstream/handle/10138/155612/SY_4_2015.pdf?sequence=4).
- Directive (EU) 2018/851 of the European Parliament and of the Council amending Directive 2008/98/EC on waste. OJ L 150, 14.6.2018, 109-140, Available: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0851&from=EN>.
- EllenMacArthur Foundation (2017) Circular Economy Overview. Available: <https://www.ellenmacarthurfoundation.org/circular-economy/overview/concept>, accessed 4.4.2019.
- Environment Committee (2018) Ympäristövaliokunnan mietintö YmVM 4/2018 vp - HE 195/2017 vp. Available: [https://www.eduskunta.fi/FI/vaski/Mietinto/Sivut/YmVM\\_4+2018.aspx](https://www.eduskunta.fi/FI/vaski/Mietinto/Sivut/YmVM_4+2018.aspx).
- European Bioplastics (2015) Mechanical Recycling, Fact sheet Apr 2015, Available: [https://docs.european-bioplastics.org/publications/bp/EUBP\\_BP\\_Mechanical\\_recycling.pdf](https://docs.european-bioplastics.org/publications/bp/EUBP_BP_Mechanical_recycling.pdf), accessed 18.1.2019.
- European Commission (2015) Closing the loop. Commission adopts ambitious new Circular Economy Package to boost competitiveness, create jobs and generate sustainable growth. European Commission's press release. Available: [http://europa.eu/rapid/press-release\\_IP-15-6203\\_en.htm](http://europa.eu/rapid/press-release_IP-15-6203_en.htm), accessed 29.11.2018.
- European Commission (2018a) New waste rules will reinforce EU's position as the global front-runner in waste management and recycling, Available: [http://ec.europa.eu/environment/pdf/27\\_02\\_2018\\_news\\_en.pdf](http://ec.europa.eu/environment/pdf/27_02_2018_news_en.pdf), accessed 20.11.2018.
- European Commission (2018b) Circular Economy: New rules will make EU the global front-runner in waste management and recycling. European Commission's press release. Available: [http://europa.eu/rapid/press-release\\_IP-18-3846\\_en.htm](http://europa.eu/rapid/press-release_IP-18-3846_en.htm), accessed 7.11.2018.
- European Commission (2018c) Single-use plastics: New EU rules to reduce marine litter. European Commission's press release. Available: [http://europa.eu/rapid/press-release\\_IP-18-5\\_en.htm](http://europa.eu/rapid/press-release_IP-18-5_en.htm), accessed 7.11.2018.
- European Commission (2018d) Communication from the Commission to the European parliament, the Council, the European economic and social committee and the Committee of the regions. A European Strategy for Plastics in a Circular Economy. Available: <http://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy.pdf>, accessed 10.12.2018.
- European Commission (2018e) Single-use plastics: Commission welcomes ambitious agreement on new rules to reduce marine litter. European Commission's press release. Available: [http://europa.eu/rapid/press-release\\_IP-18-6867\\_en.htm](http://europa.eu/rapid/press-release_IP-18-6867_en.htm), accessed 4.4.2019.
- Fontell P., Heikkilä P. (2017) Model of circular business ecosystem for textiles, VTT Technology 313, Available: <http://www.vtt.fi/inf/pdf/technology/2017/T313.pdf>.
- Haapala E., Johansson M., Kankare E., Nurminen M., Saukkoriipi O., Silokoski A. (2018) Tekstiilien EKO-merkintä-kartta, Available: [https://storage.googleapis.com/turku-amk/2018/04/haapala-et-al\\_tekstiilien-eko-merkinta-kartta\\_poster.pdf](https://storage.googleapis.com/turku-amk/2018/04/haapala-et-al_tekstiilien-eko-merkinta-kartta_poster.pdf), accessed 4.4.2019.
- Harlin A. (2018) Roadmap for recycled textiles in Finland in 2020's, Telaketju-seminar, Hanasaari Espoo, 18.9.2018, Available: [https://storage.googleapis.com/turku-amk/2018/09/1-2\\_harlin.pdf](https://storage.googleapis.com/turku-amk/2018/09/1-2_harlin.pdf), accessed 4.4.2019.

- HE 195/2017. Hallituksen esitys eduskunnalle laiksi jätelain muuttamisesta (a proposal of the Government to Finnish Parliament on reformation the waste law). Available: <https://www.finlex.fi/fi/esitykset/he/2017/20170195>.
- HE 248/2018. Hallituksen esitys eduskunnalle laiksi jätelain muuttamisesta (a proposal of the Government to Finnish Parliament on reformation the waste law). Available: <https://www.finlex.fi/fi/esitykset/he/2018/20180248>.
- Heikkilä J. (2018) Future steps of postconsumer textile refining in Finland, Telaketju-seminar, Hanasaari Espoo, 18.9.2018, Available: <https://storage.googleapis.com/turku-amk/2018/10/2-5-heikkilaj.pdf>, accessed 4.4.2019.
- Heikkilä P. (ed.), Fontell P., Kamppuri T., Mensonen A., Määttä M., Pitkänen M., Raudaskoski A., Vehmas K., Vehviläinen M., Harlin A. (2018) The Relooping Fashion Initiative, VTT Research Report VTT-R-01703-18, 73 p.
- Heikkilä J., Heikkilä P. (2018) Tekstiilit varmasti kiertoon: Haasteet ja riskien hallinta tekstiilien kierrätyksessä. VTT Technology 343, Available: <https://www.vtt.fi/inf/pdf/technology/2018/T343.pdf>.
- Hinkka V., Heikkilä P., Harlin A. (2019), Tekstiilikierrätyksen prosessien kustannusmallinnus. Tutkimusraportti VTT-R-06611-18, 37 p.
- ICSC (2018) ILO, WHO and EC, International Chemical Safety Cards Database. Available: [https://www.ilo.org/safework/info/publications/WCMS\\_113134/lang--en/index.htm](https://www.ilo.org/safework/info/publications/WCMS_113134/lang--en/index.htm).
- Kamppuri T., Pitkänen M., Heikkilä P., Auranen A., Saarimäki E., Cura K., Zitting J., Knuutila H., Mäkiö I. (2019a) Tekstiilimateriaalien soveltuvuus kierrätykseen. VTT Tutkimusraportti VTT-R-00091-19, 38 p.
- Kamppuri T., Heikkilä P., Pitkänen M., Hinkka V., Viitala J., Cura K., Zitting J., Lahtinen T., Knuutila H., Lehtinen L. (2019b) Tunnistusteknologiat tekstiilien kierrätyksessä. VTT Tutkimusraportti VTT-R-00092-19, 28 p.
- Kamppuri T., Heikkilä P., Saarimäki E., Pitkänen M., Mattila I., Niemeläinen M., Harlin A. (2018) Airborne dust from mechanically recycled cotton during ring spinning. A poster presentation in International conference on recycling of textiles and plastics, Brugge, Belgium 13-14.11.2018.
- Kauppalehti (2018) Yritykset viestivät ympäristöteoistaan varovaisesti - taustalla voi olla pelko kielteisestä huomiosta, 22.1.2018. Available: <https://www.kauppalehti.fi/uutiset/yritykset-viestivat-ymparistoteoistaan-varovaisesti-taustalla-voi-olla-pelko-kielteisesta-huomiosta/63470e00-69cb-3592-867b-8b492789878d>, accessed 15.1.2019.
- Laaksonen J., Salmenperä H., Stén S., Dahlbo H., Merilehto K., Sahimaa O. (2018) Kierrätyksestä kiertotalouteen. Valtakunnallinen jätesuunnitelma vuoteen 2023. Suomen ympäristö 01/2018. Ympäristöministeriö, Helsinki, 61 p. Available: <http://urn.fi/URN:ISBN:978-952-11-4774-6>
- Lanne M., Heikkilä J. (2016) Uutta riskien arviointiin! Tietopohjan merkitys ja uudistamisen keinot. VTT Technology 279, 35 + 7 p. Available: <http://www.vtt.fi/inf/pdf/technology/2016/T279.pdf>.
- Materiaalitori (2019) Jätteiden ja sivuvirtojen tietoaalusta. Available <https://www.materiaalitori.fi/>, accessed 11.4.2019.
- Ministry of Environment (2017) Jätedirektiiveistä alustava sopu EU:ssa — uusia kunnianhimoisia kierrätystavoitteita jätteille. Press release. Available [http://www.ym.fi/fi-FI/Ajankohtaista/Tiedotteet/Jatedirektiiveista\\_alustava\\_sopu\\_EUssa\\_\(45460\)](http://www.ym.fi/fi-FI/Ajankohtaista/Tiedotteet/Jatedirektiiveista_alustava_sopu_EUssa_(45460)), accessed 4.4.2019.
- Ministry of Environment (2018a) Vähennä ja vältä, kierrätä ja korvaa. Muovitiekartta Suomelle. Available: <file:///C:/Users/mpmarjah/Downloads/V%C3%A4henn%C3%A4%20ja%20v%C3%A4lt%C3%A4>

[4.%20Kierr%C3%A4t%C3%A4%20ja%20korvaa.%20Muovitiekartta%20Suomelle%20\(3\).pdf](#), accessed 4.4.2019.

Ministry of Environment (2018b) Jätteiden ja sivuvirtojen tietoaustaa aletaan toteuttaa ja testata käyttäjien kanssa. Press release. Available: [http://www.ym.fi/fi-FI/Ymparisto/Jatteen/Jatteiden\\_ja\\_sivuvirtojen\\_tietoaustaa\\_a\(48637\)](http://www.ym.fi/fi-FI/Ymparisto/Jatteen/Jatteiden_ja_sivuvirtojen_tietoaustaa_a(48637)), accessed 4.4.2019.

Ministry of Environment (2018c) Kertakäyttömuoveja koskevasta lakiesityksestä sopu. Press release. Available: [http://www.ym.fi/fi-FI/Ymparisto/Jatteen/Kertakayttomuoveja\\_koskevasta\\_lakiesityk\(48857\)](http://www.ym.fi/fi-FI/Ymparisto/Jatteen/Kertakayttomuoveja_koskevasta_lakiesityk(48857)), accessed 4.4.2019.

Nikula T. (2019) Personal communication 7.1.2019 (by e-mail) related to European Commission's directive proposal on single-use plastics.

Pitkänen M., Heikkilä P., Kamppuri M. (2018) Safety issues related to textile recycling. A poster in Telaketju networking seminar 10.4.2018 Innopoli, Espoo. Available: <https://telaketju.turkuamk.fi/in-english/safety-issues-related-to-textile-recycling/>, accessed 4.4.2019.

Ragaert K., Delva L., Van Geem K. (2017) Mechanical and chemical recycling of solid plastic waste, *Waste Management* **69**, 24-58.

Salmenperä H. (2017) Poistotekstiileihin kytkeytyvät juridiset ja hallinnolliset tulokset sekä menettelyt. SYKE. 12 p. Available: [https://storage.googleapis.com/turku-amk/2018/02/termit-jalainsaadanto\\_syke.hannasalmenpera.2017.pdf](https://storage.googleapis.com/turku-amk/2018/02/termit-jalainsaadanto_syke.hannasalmenpera.2017.pdf), accessed 4.4.2019.

Salonen A.O., Fredriksson L., Järvinen S., Kortenien P., Danielsson J. (2014) Sustainable Consumption in Finland—The Phenomenon, Consumer Profiles, and Future Scenarios, *International Journal of Marketing Studies* **6**(4), 59-82.

Sten S. (2018) Kierrätyksestä kierrätyslouteen - Ympäristöministeriön ajankohtaiskatsaus. Jätelautakuntien neuvottelupäivät 15.11.2018, Seinäjoki, Finland.

STM (2018) HTP-arvot 2018. Haitallisiksi tunnetut pitoisuudet. Sosiaali- ja terveysministeriön julkaisuja 9/2018, 105 p.

Swedish Chemicals Agency (2014) Chemicals in textiles – Risks to human health and the environment. Report from a government assignment. Report 6/14, Arkitektkopia, Stockholm, 142 p. Article no. 361130. Available: <https://www.kemi.se/files/8040fb7a4f2547b7bad522c399c0b649/report6-14-chemicals-in-textiles.pdf>, accessed 4.4.2019.

Tulli (2017) Tullin kulutustavaravalvonnan tuloksia vuodelta 2017. Available: <http://tulli.fi/documents/2912305/4756721/Tullin+kulutustavaravalvonta+2016+yhteenveto.pdf/112ac442-94df-4dc7-9f87-c62b59eb3ab9>, accessed 4.4.2019.

Tuomi T., Lappalainen L., Laaja T., Hovi H., Svinhufvud J. (2012) Haihtuvien orgaanisten yhdisteiden kokonaispitoisuuden (TVOC) tavoitetasot teollisten työympäristöjen yleisilmassa. Tavoitetaso TY-01-2012, 17.4.2012, 10 p. Available: <https://www.ttl.fi/wp-content/uploads/2016/12/TVOC-tavoitetasot.pdf>, accessed 4.4.2019.

United Nations (1987) Our Common Future, Report of the World Commission on Environment and Development, Brundtland Report, 300 p. Available: <http://www.un-documents.net/our-common-future.pdf>, accessed 4.4.2019.

Viljakainen S. (2016) Tekstiilien tuontivalvonta Tullilaboratoriossa, 10.5.2016. Available: [https://s3-eu-west-1.amazonaws.com/stjm/uploads/20160516081718/Tekstiilien-tuontivalvonta-Tullilaboratoriossa\\_SiruViljakainen-Tullilaboratorio.pdf](https://s3-eu-west-1.amazonaws.com/stjm/uploads/20160516081718/Tekstiilien-tuontivalvonta-Tullilaboratoriossa_SiruViljakainen-Tullilaboratorio.pdf), accessed 4.4.2019.